

Exploring the impact of emissions trading on Schiphol

Assessing the redistribution of passengers between Schiphol and Dubai airport



Laurens J. Priem

MSc Thesis

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Preface

Writing this thesis has been a challenging and rewarding experience. It gave me great insight in the functioning of an emissions trading scheme and the dynamics within the aviation sector. This research would not have been possible without the support of many people, of which I would like to mention a few:

First of all, I would like to thank Ebel Kemeling and Matthijs Baan for providing me with the opportunity to write my thesis at Spring Associates and for steering my research in new directions. Also, I would like to profoundly thank my supervisors at the TU Delft and Spring Associates for their support and contributions to my work: Jan Anne Annema and Michiel Sluimers for reviewing all my concepts, providing useful input and giving me confidence in my work, Bert van Wee and Rolf Künneke for their guidance and expertise, and Laurens de Vries for all the support during the initiation phase of my research.

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Laurens J. Priem

Summary

Concerns for rising global temperatures and climate change have led to the development of the European Union Emissions Trading Scheme (EU ETS), which aims to realize the reduction of emissions of greenhouse gases such as carbon dioxide (CO₂) in a cost-effective way. As of 2012, the aviation sector will be included in this scheme, requiring airlines to acquire CO₂ emission rights for flights arriving at or departing from a European airport. For Schiphol Group, owner of Amsterdam Airport Schiphol, it is unclear how this upcoming inclusion will influence the position of Schiphol airport, and whether it necessary to implement measures to mitigate this potential impact. To elucidate this matter, in this research the following research question has been addressed:

What could be the impact of the inclusion of aviation in the European Emissions Trading Scheme on the position of Schiphol airport, and what strategy should Schiphol Group pursue to mitigate this impact?

Because Schiphol Group's core business is passenger transport, this research has focused on the *redistribution of passengers*: if the inclusion of aviation in the EU ETS causes a significant cost difference between European and non-European airports, the latter could gain market share at the expense of European airports in certain market segments. Since Schiphol has a large share of transfer passengers who are not bound to use Schiphol as their connecting airport, it could be particularly vulnerable to this effect.

The impact has been quantified by assessing what share of Schiphol passengers could switch to Dubai airport during phase III of the EU ETS that commences in 2013 and ends in 2020. To this end a neoclassical approach has been chosen: after determining the utility of route alternatives the redistribution has been calculated in several scenarios using a Multinomial Logit model. The focus of this study is on Dubai because it is one the airports most likely to benefit from the inclusion of aviation in the EU ETS at the expense of Schiphol, as it has ample capacity and focuses largely on the same market segments. In this way, the results can be used as a first indicator of the magnitude of the overall impact of the EU ETS. The required data for this model have been acquired from several interviews with KLM and Schiphol and from other studies in this field. In addition, data from estimates have been used.

Another important business area for Schiphol Group that could indirectly be affected by a redistribution of passengers is the real estate sector: a reduction in passenger numbers could affect the network of destinations served from Schiphol, thereby impacting the economic attractiveness of the region. To assess this effect, the impact on the *network quality* of Schiphol has been estimated as well, as it influences both the passengers and the real estate sector. Furthermore, because Schiphol Group aims to grow in a sustainable manner, it has been assessed how this redistribution could induce *carbon leakage*, the effect that carbon-emitting activities shift towards non-EU countries, thereby evading a European emissions cap.

The outcomes of this research indicate that the direct impact of the inclusion of aviation in the EU ETS on Schiphol airport is limited: the total number of passengers that will switch to Dubai during phase III can be expected to be between 0.3% and 1% of all passengers at Schiphol. For specific market segments this impact could be larger: 1-11% of transfer passengers between North America and Asia and 2-8% of transfer passengers between

Europe and Asia could switch to Dubai. However, currently these market segments make up only a minor share of all transfer passengers at Schiphol. In addition, 4-11% of all direct passengers between Schiphol and Asia could decide to fly with a stopover at Dubai, but this will not directly affect Schiphol as these passengers still have their final origin or destination there. Yet, KLM and other carriers at Schiphol could be affected by this redistribution, as Dubai-based carriers could employ their own feeder flights to bring passengers to their hub. Because of the strong relation between KLM and Schiphol, the position of the latter could be indirectly influenced in this way.

Based on the estimated redistribution it can be concluded that the network quality and economic attractiveness of Schiphol are hardly affected by the inclusion of aviation in the EU ETS: it is expected that on almost all current destinations at least a daily frequency can be maintained, which is deemed adequate by most companies that regularly use Schiphol. However, in conjunction with other factors like the liberalization of the aviation sector and the aftermath of the current economic crisis, it is possible that the EU ETS provides the 'tipping point' that results in a strong reduction of the network quality of Schiphol. Also, it should be noted that on an individual carrier level, even this limited redistribution could cause the termination of service on certain destinations, because of the small operating margins of airlines.

The resulting carbon leakage could amount to up to 2% of all emissions at Schiphol, 0,3% of all emissions in the Netherlands under the EU ETS. As such, the environmental impact is limited. However, if a comparable redistribution takes place at other European airports as well, it could negate European efforts to reduce CO₂ emissions.

Based on these outcomes, there is no urgency for Schiphol Group to pursue a strategy to mitigate the impact of the EU ETS. Still, it is recommended to implement a 'no-regret' policy consisting of three pillars: first of all, monitoring several key indicators will enable Schiphol Group to timely anticipate a larger impact of the EU ETS than expected. These indicators include expansion plans of carriers at Dubai and European policies that could influence the price of an emission allowance. Secondly, additional research should resolve uncertainties with regard to the outcomes of this study, for example by developing a method to integrate multiple airports in the model, and by developing a more accurate method to estimate the actual overlap between airports in terms of passenger numbers. Thirdly, several low-cost measures could be implemented in a precautionary way or in case the monitoring program indicates the impact of the EU ETS could be larger than predicted. These measures include emphasizing Schiphol's green image and lobbying with other airports in Europe for a European regulation that allows airports more control over slot allocation and gives the possibility to differentiate airport taxes.

It should be noted that due to the chosen approach and modelling technique and the lack of available data, certain assumptions and simplifications had to be made. These could limit the validity of the outcomes of this research. If these uncertainties are reduced, the methodology developed in this report could also be used to project the longer-term impact of the EU ETS on Schiphol or other comparable airports.

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Part I – Problem exploration and research framework

1. Introduction

Giovanni Bisignani, Director General and CEO of the International Air Transport Association (IATA), declared “this is the most difficult situation that the industry has ever faced”, in his *State of the Air Transport Industry* speech in Malaysia in June 2009, addressing the economic crisis. He revealed airlines lost €10.5 billion in the previous year as result of “skyrocketing oil prices in the first half of 2008 and global recession in the second half”. In addition, he expressed his concern that recovery should not be expected soon (IATA, 2009b). Meanwhile, airports and airlines in the Gulf region are heavily investing to expand their capacity in order to develop a sophisticated international network. As they are perfectly positioned between Asia and Europe, these carriers could pose a major threat to European airlines and airports (O’Connell, 2006). A recent press release by the IATA underlines this threat: even as European carriers face a 9% reduction in passenger demand in May compared with the same month in 2008, and struggle to maintain load factors by reducing their capacity, Gulf carriers bucked this trend by achieving a 9,5% *increase* in demand and a 14,5% expansion of capacity (IATA, 2009a).

At the same time, the European Commission has adopted a directive to include aviation in the European Emissions Trading Scheme (EU ETS). This could increase operational costs for carriers that operate flights to Europe and, given the conditions described above, be the proverbial ‘straw that breaks the camel’s back’ for the European aviation sector, possibly resulting in the bankruptcy of carriers or airports. One airport that could be seriously affected is Amsterdam Airport Schiphol (Schiphol), mainly due to its large share of transfer passengers. To assess this impact for Schiphol Group, owner of Schiphol, more insight is needed in the particular effects of emissions trading. Therefore, in this thesis it has been explored how the EU ETS could induce a redistribution of passengers between Schiphol and Dubai airport. Dubai has been chosen as it is one the airports most likely to benefit from the inclusion of aviation in the EU ETS, because of its geographical location and expansion programmes. Thus, the results can be used as a first indicator of the magnitude of the overall impact of the EU ETS on the aviation sector. In addition, the developed methodology could be applied to other airports as well. In the next paragraphs an overview is given of Schiphol, the inclusion of aviation in the EU ETS and the exact scope of research.

1.1. Schiphol Group

Schiphol Group is an airport operator that operates several airports in the Netherlands and is a shareholder in several airports around the globe. The core activity of Schiphol Group is the operation of Amsterdam Airport Schiphol (Schiphol): besides aviation-related business related to cargo and passenger transport, this comprises activities in the field of consumer business (mainly the operation of shops and car parks) and in the field of real estate. Schiphol’s main shareholders are the Dutch government (69,77%) and the Municipality of Amsterdam (20,03%) (Schiphol Group, 2008). Based on this public ownership, Schiphol Group aims to realize *growth in a sustainable matter* (Schiphol Group, 2009). The following figure shows how sub-goals related to these business areas are assumed to contribute to this goal:

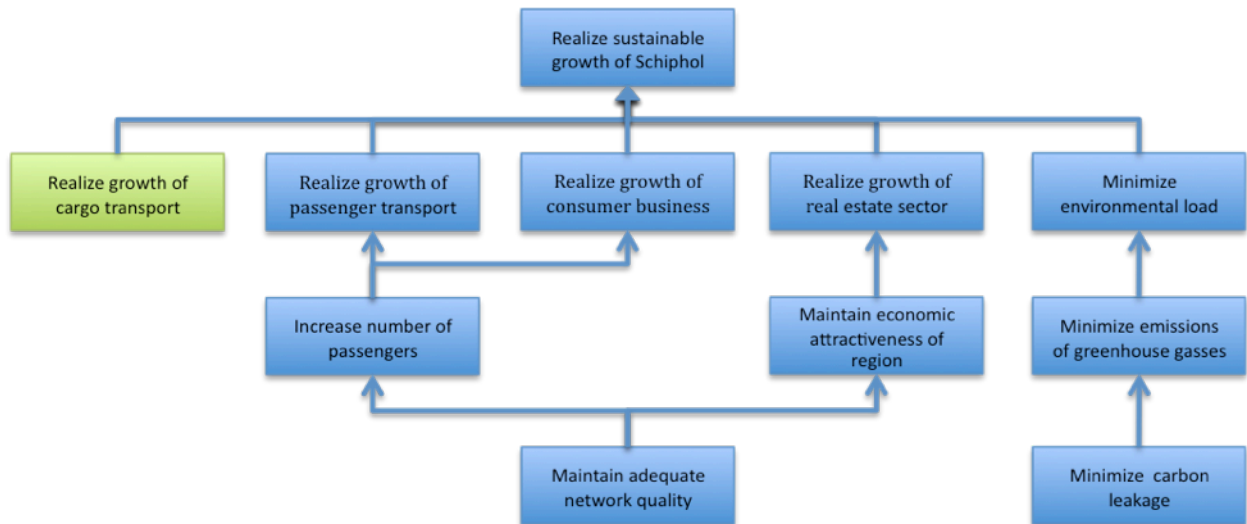


Figure 1.1: goals and sub-goals for Schiphol Group for Schiphol airport.

It should be noted that this overview is not comprehensive, but merely aims to illustrate the scope of this research. Therefore goals are not specified on a more operational level, and sub-goals that are outside of the scope of this research are shown in green and are not further elaborated. Based on the assumed goal of Schiphol Group and the different business areas in which it is active this research has only focused on the following aspects, as they are deemed most relevant:

- Number of passengers at Schiphol
- The network quality of Schiphol
- The economic attractiveness of Schiphol
- Carbon leakage

1.2. Schiphol airport

Schiphol is the main airport of the Netherlands: in terms of passenger numbers it is Europe's fifth-largest airport with nearly 48 million passenger movements in 2007, and third with respect to cargo with 1.6 million tons cargo transported (Schiphol Group, 2007b): Figure 1.2 shows the position of Schiphol compared with other major European airports in terms of transport movements:

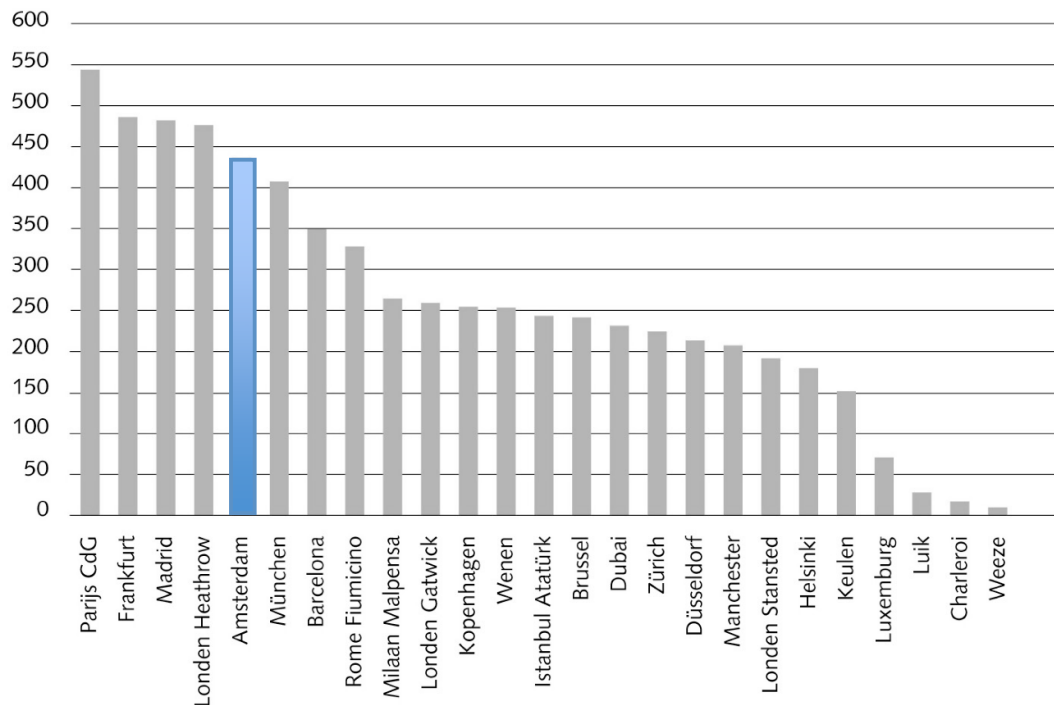


Figure 1.2: number of air transport movements (x1000) per airport in 2007 (taken from Kolkman and Korteweg, 2009)

In terms of connectivity, Schiphol is a ‘major league’ airport as well: it has 157 European and 110 intercontinental scheduled destinations (Schiphol Group, 2007c). In addition, an even larger number of destinations can be reached with an indirect flight, for example with a stopover at a North-American hub. The total number of city pairs¹ connected through KLM surpasses 80.000 (Schiphol Group, 2008). This high network connectivity is of great significance for the region and the *mainport* function of the Netherlands: in a global economy it is of great importance that the *Randstad*² has direct connections with important economic regions around the world (Schiphol Group, 2007a). The mainport concept is further described in the box below:

Box 1.1: Schiphol as mainport

The *mainport* concept is often used in policy discussions concerning Schiphol but remains ambiguous. For example, Gordijn et al. (2007) define a mainport as an “*economical engine that generates employment that is directly related to the airport and is induced by the high connectivity of the airport*”. Stratagem Strategic Research (2004) uses a wider definition: “*the metropolitan area that functions as an essential axis between the international flows of passengers, cargo and information and the national network [...]*”. In these definitions, (Stratagem Strategic Research, 2004) two elements stand out: international accessibility for cargo and persons, and the resulting competitive advantage for international firms, mainly European distribution centres and headquarters (Gordijn et al., 2007). As a result, Schiphol airport has attracted many European headquarters, distribution centres and other large companies: in the last decades 50% of all American and 60% of all Japanese companies with a European distribution centre have settled in the vicinity of Schiphol (Schiphol Group, 2008).

¹ This refers to all possible ‘one-stop city pairs’: cities connected with each other with one stopover at Schiphol through the network of KLM and its Skyteam partners (Schiphol Group, 2007d)

² The four largest Dutch cities and surrounding areas

Looking at the size of Schiphol's hinterland or *catchment area*, its relative connectivity is very high: the size of the hinterland, defined by the number of inhabitants living within 200 km of Schiphol, is 34 million. Other airports with a comparable hinterland have much less direct intercontinental connections (Air France KLM, 2008). Figure 1.3 below shows the catchment area of Schiphol:



Figure 1.3: catchment area of Schiphol (taken from Air France KLM, 2008)

1.3. Dependency on transfer segment

This large network of destinations can be maintained because, in addition to these 'hinterland-passengers', a large share of the passengers at Schiphol has a different origin and final destination and uses Schiphol only as a connecting hub between flights. In 2007, these 'transfer' passengers constituted 41% of all passenger transport (Schiphol Group, 2007c). For intercontinental flights, this number is even higher: for example, on intercontinental flights operated by KLM (Schiphol's largest carrier) transfer passengers make up 70 percent of all passengers on average. In figure 1.4 below the red bars show the share of transfer passengers on flights operated by KLM to most intercontinental destinations.

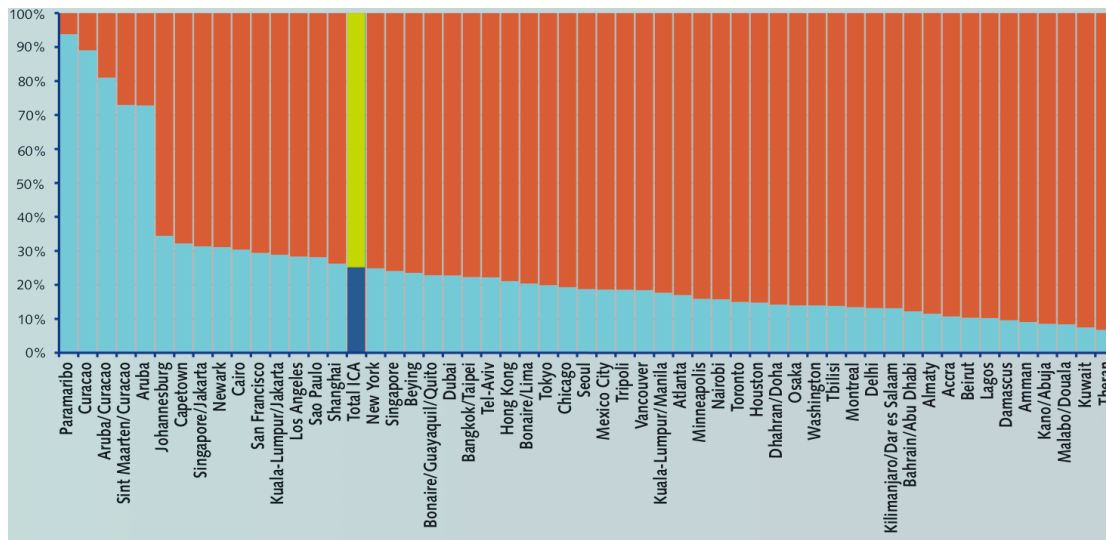


Figure 1.4: share of transfer passengers (in red) on intercontinental KLM flights (taken from Ministerie V & W, 2007)

As shown in this figure, on flights to certain destinations such as Tehran and Kuwait the share of transfer passengers is as high as 90%. The yellow bar in the middle shows the average share of transfer passengers on all intercontinental (ICA) flights.

1.4. Inclusion of aviation in the EU ETS

One factor that could influence the current position of Schiphol is the inclusion of aviation in the European Emissions Trading Scheme (EU ETS): to this end, in 2008 the European Union has adopted a directive, requiring airlines to acquire CO₂ emission rights for flights that arrive at or depart from a European airport (European Commission, 2008). This scheme is explained in more detail in section 2.2.

The decision to include aviation in the EU ETS has been based on an extensive impact assessment that has been carried out by the European Commission. According to this assessment, “*competition between airlines would not be expected to be significantly affected*”, because all airlines would be treated equally. Similarly, competition between airports would not be significantly affected because “*...forecasted demand growth remains high*”. According to the assessment, 0.03% of all passengers in Europe would shift to airports outside of Europe as a result of the inclusion of aviation (European Commission, 2006b). However, other studies show completely different estimations: CE Delft & MVA Consultancy (2007) estimate this number to be -1.9%, while Ernst & Young (2007) project a 1% shift of passengers. The large variation in these predictions shows *there is no consensus on the expected overall impact of the EU ETS on the European aviation sector*.

1.5. Uncertainty on effect of EU ETS on individual airport level

Closer examination of these reports reveals different underlying assumptions, mainly with respect to the assumed cost pass-through rate³, price elasticity of demand⁴ and price setting mechanisms. Furthermore, the effects on an individual airport depends on specific properties like the geographical location, the size of the hinterland and the share of market segments served, as acknowledged by several reports such as that of CE Delft (CE Delft & MVA Consultancy, 2007). More specifically, it appears that the market segment consisting of intercontinental routes could be more severely affected: on these routes the EU ETS could induce a redistribution of passengers to hubs located close to Europe (Scheelhaase and Grimme, 2007). For example, intercontinental passengers currently flying through Schiphol could be inclined to switch to Dubai if the relative attractiveness of routes via Schiphol diminishes vis-à-vis routes via Dubai. This would be the result of a price difference caused by a higher number of allowances required for flights passing through Europe, all other factors being equal. Figure 1.6 and figure 1.7 below show this effect for two exemplary routes:



Figure 1.5: additional allowances required for flight from Bangalore to New York through European airport (taken from Air France KLM, 2008)

The figure above shows that if a passenger flying from Bangalore to New York chooses to fly through Europe (in this case Paris Charles De Gaulle), for both legs of the route allowances (permits) will need to be acquired (X + X permits). On the other hand, if he flies through Dubai, no allowances are required at all.

³ *Cost pass-through rate* refers to the degree to which costs caused by the EU ETS are passed on to customers. This concept is further described in section 3.1.2

⁴ This indicates the sensitivity of flight demand to price changes

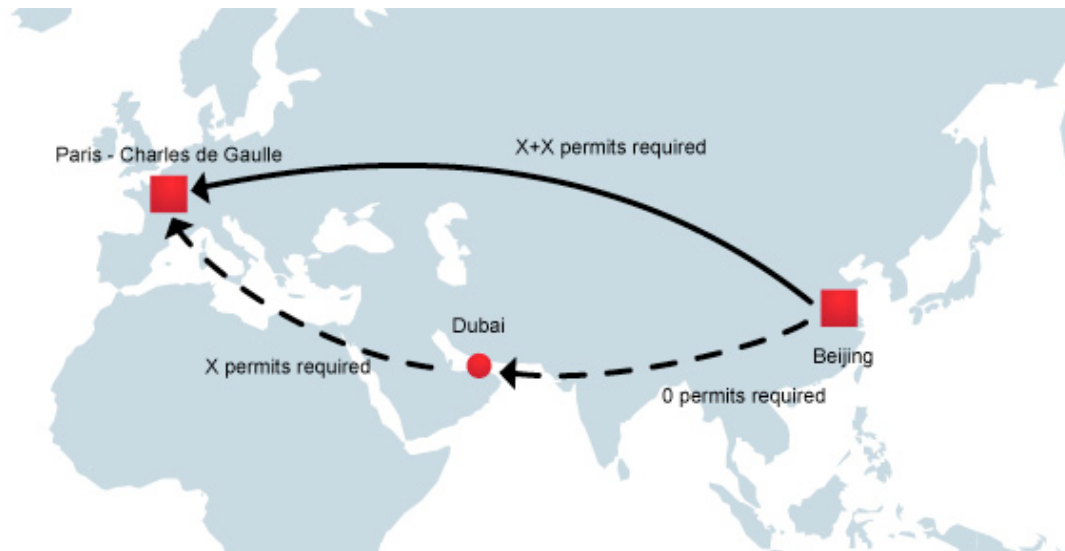


Figure 1.6: additional allowances required for direct flight from Beijing to Paris (taken from Air France KLM, 2008)

Similarly, if a passenger travelling from Beijing to Europe chooses a direct flight, allowances will be required for the whole flight ($X + X$). On the other hand, if he has a stopover at Dubai, allowances will only be required for the latter part of his itinerary (X).

1.6. Problem formulation

As shown in section 1.4, there is no scientific consensus on the impact of the EU ETS on the aviation sector. Furthermore, since Schiphol has a large share of intercontinental transfer passengers who are not bound to use Schiphol as their connecting airport, it is particularly vulnerable to competition from hubs that focus on the intercontinental transfer market. Thus, if the inclusion of aviation in the EU ETS causes a significant cost difference with non-European airports, the latter could potentially gain market share at the expense of Schiphol. Currently, there is no clear insight to what extent this effect could take place, nor is it clear to what extent this will affect the network of destinations served by Schiphol and to what extent it will induce carbon leakage. As a result, it is not clear for Schiphol group if it is necessary to adopt measures to mitigate this impact.

1.7. Research objectives and research questions

Several non-European hubs could potentially gain market share at the expense of Schiphol: in the Gulf region alone three major airports are being expanded, all focusing on long-haul transfer passengers. Furthermore, airports like Istanbul and airports located on the East Coast of the United States could gain market share. However, not all of these airports pose an equal threat, for example because of capacity constraints or regulatory limitations. Hence, in this study the focus is on Dubai only: it is one of the airports most likely to benefit from the inclusion of aviation in the EU ETS at the expense of Schiphol: in an interview, KLM's CEO Leo van Wijk described Dubai as "a major threat to Schiphol" (Nieuwsblad Transport, 2006). Not only does it focus solely on intercontinental transfer passengers, due to massive investment programs it will soon have ample airport and fleet capacity. In addition it is well positioned for flights between important destinations in Asia and Europe

(O'Connell, 2006). In this way, the redistribution of passengers between Schiphol and Dubai could be a good indicator of the possible overall effect of the EU ETS for Schiphol: a limited impact of Dubai could imply the overall effects for Schiphol are limited as well. Alternatively, if the impact is very large, this is an indicator that other non-European hubs could gain market share as a result of the EU ETS as well, showing the urgency and the necessity for additional research.

As such, this research aims to provide insight in the significance and possible consequences of the inclusion of aviation in the European Emissions Trading Scheme for Schiphol Group as owner of Amsterdam Airport Schiphol. By providing quantitative insight in the share of passengers possibly switching to Dubai, one of the major upcoming competitors of Schiphol, it gives a first indication to the magnitude of this impact. Furthermore, insight is provided in the effect on the network quality of Schiphol and the scale of possible carbon leakage⁵. In addition, by showing the mechanisms behind this impact, a starting point for the formulation of strategies to mitigate this impact is provided.

In summary, the prime objective of this research is *to provide Schiphol Group with insight to what extent the EU ETS could cause a redistribution of passengers from Schiphol to Dubai, to give a better understanding of indirect effects and to show insight in possible mitigation measures*. To this end, the following research questions have been formulated:

Main research question

What could be the impact of the inclusion of aviation in the European Emissions Trading Scheme on the position of Schiphol airport, and what strategy should Schiphol Group pursue to mitigate this impact?

Sub research questions

- 1. To what extent could the inclusion of aviation in the EU ETS induce a redistribution of passengers from Schiphol to Dubai?*
- 2. How could this redistribution differ between several market segments served from Schiphol?*
- 3. How could this redistribution affect the network quality and economic attractiveness of Schiphol?*
- 4. How could this redistribution cause carbon leakage?*
- 5. What are the main drivers for this redistribution of passengers?*
- 6. What strategy should Schiphol Group pursue to mitigate this impact?*

⁵ the shift of carbon-emitting activities to outside the EU, thereby voiding European efforts to reduce the emissions of carbon dioxide. This is elucidated in chapter 2.3.

1.8. Setup of study

Figure 1.7 below gives a conceptual representation to elucidate how the methods used in this thesis contribute to the goals described above:

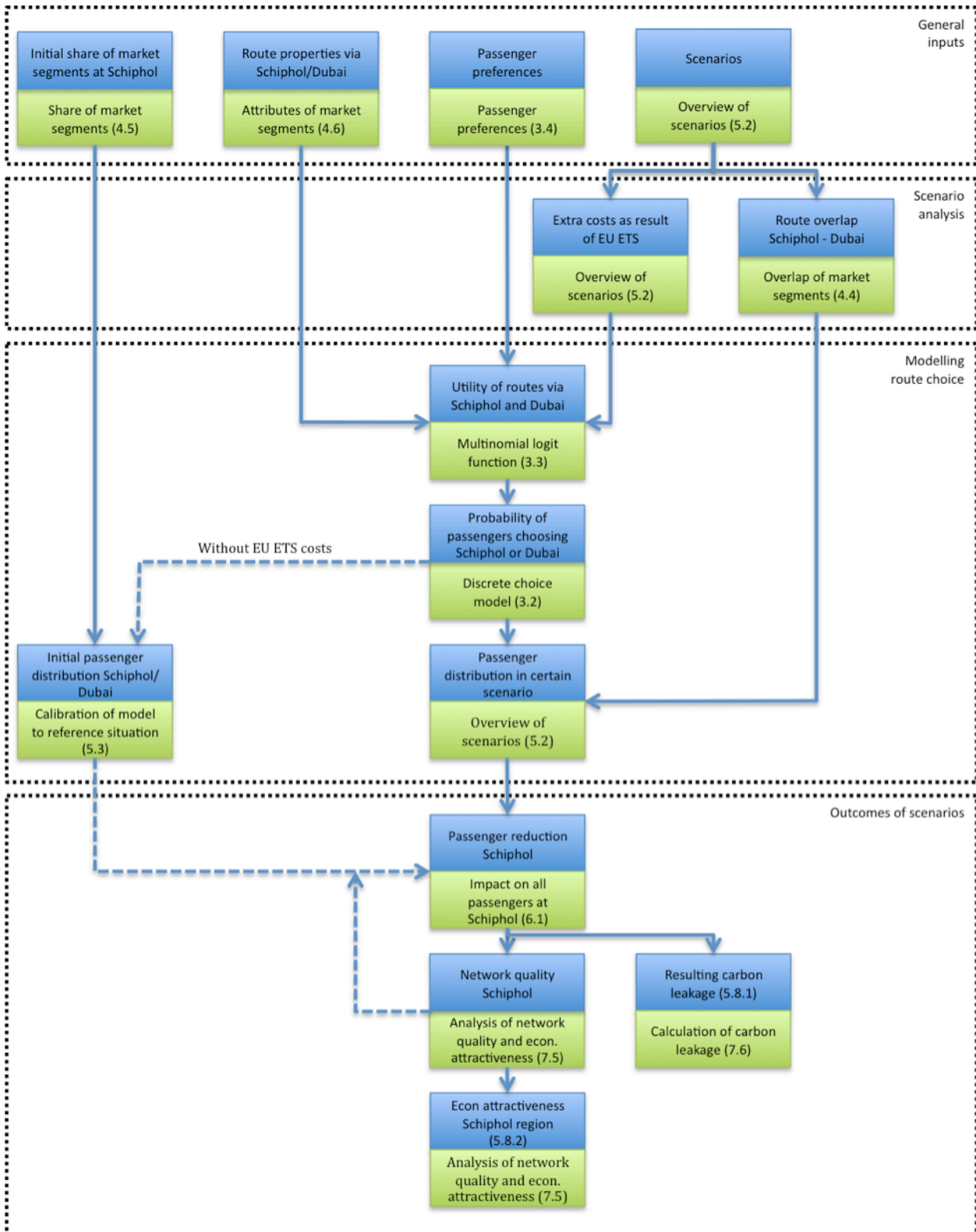


Figure 1.7: conceptual model of methods and goals (relevant section in parentheses)

In this figure, each rectangle represents a specific component of the study: the blue upper part describes the activity or outcome of the component, while each green segment describes what method or theory is used. Arrows have been used to indicate the outcomes of one component influence another component. The number in parenthesis indicates in what chapter each component is described in more detail. Underlying this figure are several key assumptions that are described in the next section.

1.9. Research approach

For this research a *neoclassical approach* has been chosen because it allows for the prediction of passenger route choice on the basis of passenger preferences and route properties: a *discrete choice model* has been developed to predict how potential Schiphol passengers are distributed between Schiphol and Dubai, based on their preferences for flight time, airfare and stopovers and the attributes of routes via both airports. A neoclassical approach is based on the following three fundamental assumptions (Weintraub):

- *Travellers have rational preferences*
- *Travellers maximize utility*
- *Travellers act independently and have complete information and full insight on the properties of route alternatives*

In addition, several key assumptions have been adopted. This is further explained in the relevant sections:

- *Focus on redistribution*

To predict the redistribution of passengers, only the choice between two route alternatives has been modelled: there is no 'no-go option'. Therefore the outcome of this research does not give any quantitative insight in the amount of passengers actually flying through Schiphol or not. This is elaborated in section 3.1.1.

- *Full cost pass-through*

It is assumed that airlines will fully pass on the costs incurred from the EU ETS to travellers. This is further explained in section 3.1.2.

- *No cross-subsidization*

It is assumed that cross-subsidisation by non-European airlines will not occur, for example by deploying cleaner aircraft on European flights and more polluting airplanes outside Europe. This is elaborated in section 3.1.3.

From these assumptions it follows that the developed model will predict the equilibrium distribution of passengers between Schiphol and Dubai under certain conditions. The estimation of indirect effects is based on this redistribution.

1.9.1. Demarcation of time

This research aims to predict the redistribution of passengers during phase III of the EU ETS that commences in 2013 and ends in 2020. To this end the predicted distribution in 2020 has been compared with the reference distribution at the beginning of 2012, just before aviation is included in the EU ETS. This period has been chosen because this will be the first phase where aviation is fully included in the EU ETS. Assessing a longer period would have little predictive value because there is great uncertainty on the conditions after 2020, regarding both economical and policy variables. Furthermore, since the outcomes of this research only project a *static, relative change* of passengers from Schiphol, for subsequent research the model could easily be adapted to project the impact after 2020. As such, the methodology developed in this report could be used to project a longer-term impact as well.

1.10. Outline of report

The following chapter concludes part I of this thesis and provides a theoretical framework, in which an overview of relevant theory is given. In part II, the properties of the model used to determine the redistribution of passengers are described: chapter 3 deals with the boundaries of the model, while in chapter 4 it is explained how the model is applied to the specific case of Schiphol and Dubai, and how input data for the model have been acquired. In chapter 5 the different scenarios used to determine the impact of the EU ETS under varying conditions are described. Part III aims to provide insight in the outcomes of this research: in chapter 6 the projected redistribution as indicated by the model is described, and in chapter 7 these outcomes are analyzed to test the robustness of these outcomes and to give insight in the expected impact of the redistribution. In chapter 8 the limited validity of these outcomes is described, as the used methodology has several important limitations. In chapter 9 a concluding overview of the results of this research is provided, and in chapter 10 recommendations for Schiphol Group are presented. Finally, in chapter 11 a wider reflection on this research is provided.

2. Theoretical framework

In this chapter, a theoretical framework is presented to provide an overview of the relevant theory and methods used in this thesis, and to clarify the main notions used: the concept of network quality is elaborated, the concept and idea behind the EU ETS are explained and the phenomenon ‘carbon leakage’ is clarified.

2.1. Network quality

The main indicator of the quality of an airport’s network is tautologically labelled as *network quality*, and is defined by Stratagem Strategic Research (2004) as “*the degree to which the network matches the international activity pattern of its users*”: the better the connection to required destinations is, the higher the network quality. The main elements of the network quality are the number of destinations reachable and the corresponding frequencies (Stratagem Strategic Research, 2004). Several indicators have been developed to show the network quality of an airport based on an analysis on individual route levels. Two important indicators are described in Box 2.1 below. However, since the redistribution of passengers has been studied at a more aggregate level in this research, those indicators have not been used. Instead it has been assessed whether an adequate network quality can be maintained cost-effectively under different scenarios. To this end in the next section the concept of *minimum network quality* is defined.

Box 2.1: indicators of network quality

Marketing Mainport indeX (MMX)

This indicator has been developed by Schiphol Group. It monitors what share of the 70 most important worldwide destinations are serviced, and at what frequency (Stratagem Strategic Research, 2004). A major shortcoming is that it does not take into account indirect connections (Van Unnik, 2009).

Connectivity Unit (CNU)

This indicator has been developed by Airneth, an initiative promoting the exchange of knowledge in the field of air transport. It measures and quantifies the performance of air transport networks, by taking into account direct and indirect connections (Burghouwt et al., 2008).

2.1.1. Minimum network quality

A *minimum network quality* can be defined from different perspectives, including the regional government, companies in the region, the aviation sector and passengers (Stratagem Strategic Research, 2004). From the perspective of Schiphol Group, all these perspectives are relevant to some extent, given the various business areas in which Schiphol group is active and the government ownership. For this research, the perspective from companies in the Schiphol region has been used. An extensive survey by Stratagem has given insight in the minimum network quality as required by those companies (Stratagem Strategic Research, 2004):

- A well-functioning European network with daily service on all current destinations
- A limited intercontinental network in which flights to key destinations in North America and Asia are operated on a daily basis
- A few specific destinations in Africa, the Middle East and South America, served at a daily frequency as well

Based on these requirements, in this research it has been assumed the minimum network quality requires a frequency of 5 flights per week on all current destinations. By combining this information with quantitative data on the annual number of passengers on several exemplary routes and calculating the break-even load factor, it is possible to assess if this minimum network quality is met under different scenarios. This is elaborated in section 7.5.

2.2. The European Emissions Trading Scheme (EU ETS)

2.2.1. Background

Concerns for climate change have led to the foundation of the United Nations Framework Convention on Climate Change (UNFCCC), and resulted in the Kyoto Protocol which aims to curb the emissions of greenhouse gases (GHG). Subsequently the European Union (EU) has ratified the protocol, and has agreed to cut its emission levels. To address the emissions of large industries, which make up 40% of EU emissions, the European Union Emissions Trading Scheme (EU ETS) has been developed. This scheme aims to realize the reduction of emissions of greenhouse gases in a cost-effective way, by setting an overall emission cap for large, energy-intensive industries, and using tradable allowances, so emission reductions will be realized in the cheapest location (Gagelmann, 2002). Currently, phase II of the EU ETS is in progress: in this phase only a limited number of industries are included, among which the steel and electricity sector. In addition, in this phase most allowances are distributed for free ('grandfathering'). However, when phase III commences in 2013 a share of the allowances will be auctioned, depending on the sector. In addition more sectors will be included, among which the aviation sector. This is described in the next section.

2.2.1. Inclusion of aviation

The aviation industry is a substantial emitter of greenhouse gases: currently, it is responsible for 2,5% to 3% of global anthropogenic carbon dioxide emissions (Scheelhaase and Grimme, 2007). In addition, there is a substantial, complex effect of non-CO₂ aviation emissions, including emissions of high-altitude NO_x, particles and water vapour leading to the formation of contrails under certain conditions (Omega, 2009). As a result, the total climate impact of the aviation sector could be around two times the impact of its carbon dioxide emissions alone, even without taking into account the highly uncertain effects of cirrus clouds (European Commission, 2008). Furthermore, the aviation sector is expected to grow substantially in the medium and long term, potentially offsetting emission reduction efforts from other sectors.

Therefore, in 2008 the European Union has adopted a directive to include aviation in the European Union Emissions Trading Scheme (EU ETS), requiring airlines to acquire CO₂ emission rights for flights that arrive at or depart from a European airport (European

Commission, 2008). Starting in 2012, the number of allowances allocated to airlines will be capped at 97% of their emissions in 2004-2006. This cap will be lowered to 95% in the 2013-2020 period. Most of these allowances will be allocated for free, but initially 15% of the allowances under the cap will be auctioned. Airlines wanting to emit more CO₂ than the number of allowances they hold will be required to buy them from other companies (Euractiv, 2008).

2.3. Carbon leakage

Carbon leakage is a possible *unintended* effect of the EU ETS. It occurs when activities that initially take place in a country where carbon emissions are charged (an abating country), are relocated to a country where no emission costs are in place (a non-abating country). As a result, global emissions will be higher since the emissions cap in the abating country remains the same while additional emissions take place in non-abating countries (Davidson et al., 2008). In this thesis the following definition for carbon leakage has been used:

The (partial) offsetting of a CO₂ emission reduction in an abating country by increasing emissions from a non-abating country as a result of shifting demand caused by carbon cost differences between the countries.

Using this definition, a quantitative definition has been formulated:

Carbon leakage [ton] = the amount of emissions in non-abating countries attributed to goods or services formerly produced in an abating country.

This 'carbon-leakage' is undesirable, both from an economical and environmental point of view: it renders a threat to European aviation and negates the goal of reducing global greenhouse gas emissions. An extensive description is provided in appendix I.

Part II - Modelling passenger route choice

3. Model development

Central to this research, a model has been developed to predict the distribution of passengers between Schiphol and Dubai under varying conditions. In this section, the key assumptions described in chapter 1.9 are explained in more detail, the specific type of model used is described and insight is given in the mathematical functioning of the model. The implications of the choices and assumptions made are described in chapter 8.

3.1. Modelling choices

An airline trip can be considered the result of a large set of choices made by a party of travellers consisting of one or more individuals. These choices include the decision to actually make the trip, the destination and the airline (Harvey, 1987). Harvey developed a conceptual framework for this set of choices that result in an airline trip. The decision hierarchy as shown in figure 3.1 below gives a possible representation of these choices:

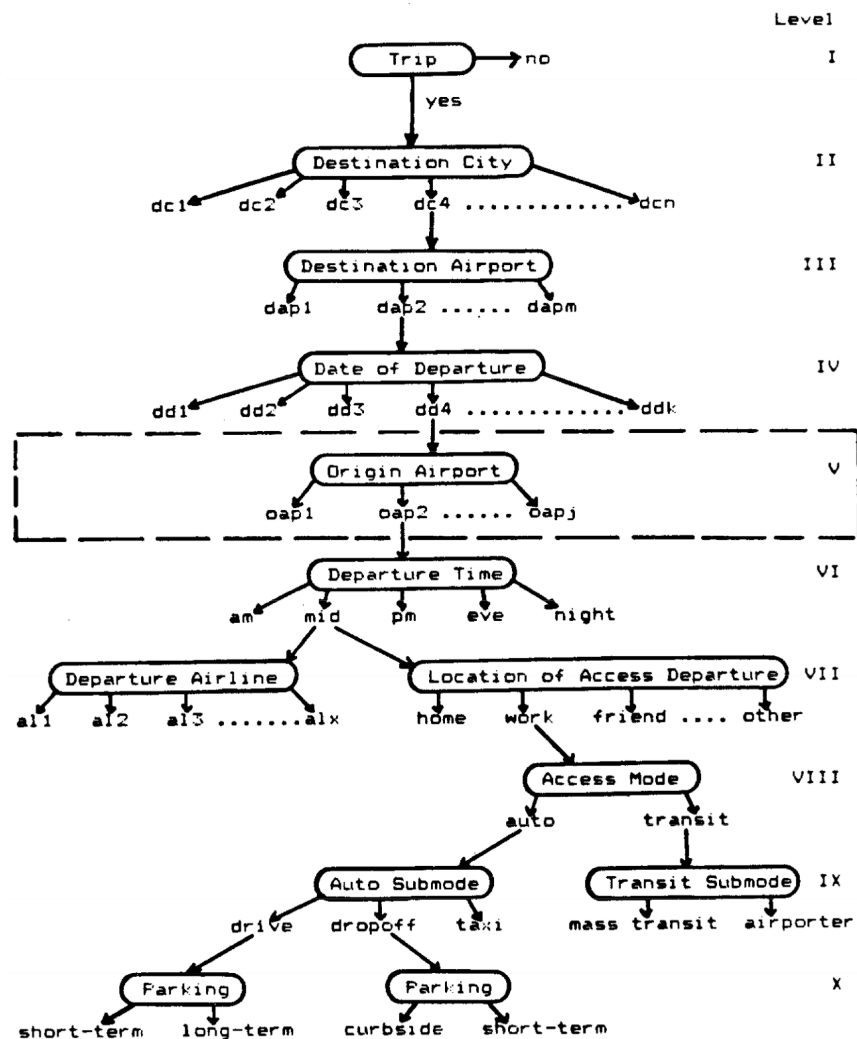


Figure 3.1: a possible decision hierarchy for air travel (taken from Harvey, 1987)

This representation is by no means exhaustive. For example, for relatively short distances alternate modalities like high-speed railroad connections must be considered as well. Which choices should be included in a model depends on the scope of the specific study.

3.1.1. Focus on redistribution

Because this research aims to model the redistribution between Schiphol and Dubai, only one subset of the choice set described by Harvey has been modelled: the choice between two possible routes, given the passenger's preferences and the attributes of both routes. This scope is illustrated in figure 3.2 below:

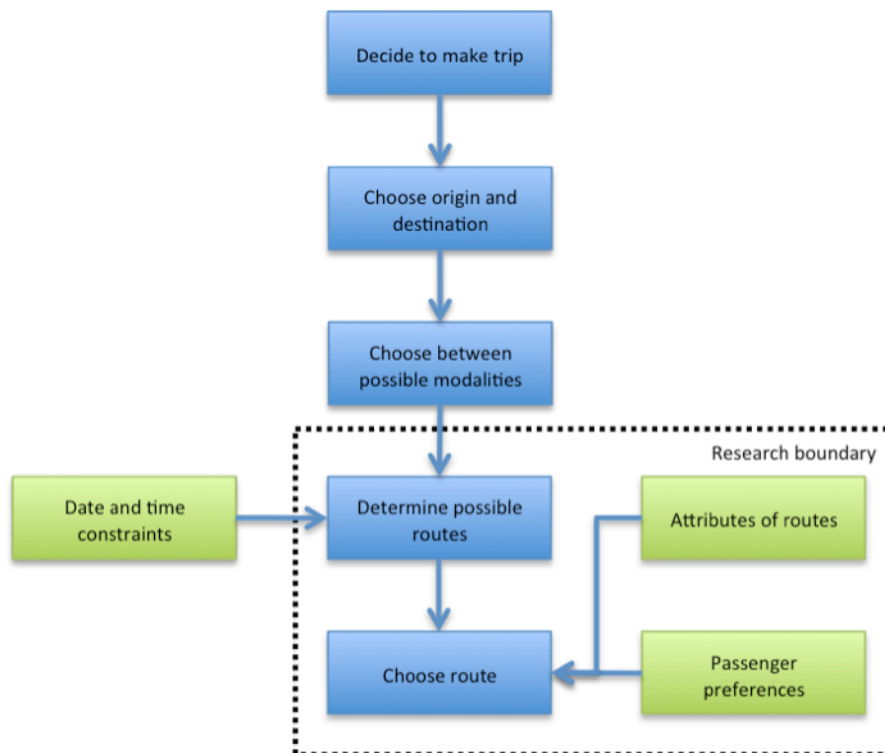


Figure 3.2: choice set included in research

In this figure the blue rectangles represent decisions by passengers, and the green rectangles represent relevant data for the choices. The dotted rectangle shows which decisions are considered in the developed model. As shown, the research gives insight in the redistribution of passengers between Schiphol and Dubai, *given the fact that they have chosen to fly to a certain destination*. To this end a *binary choice model* has been developed. In addition, to model this choice perfect inelasticity has to be assumed. This assumption is further described in section 8.1. The concept of price elasticity is described in Box 3.1 below.

Box 3.1: price elasticity of demand

By determining the responsiveness of passengers' flight demand to changes in the price of a flight, one can gain insight in the sensitivity of travellers to price changes. This sensitivity is represented by the *price elasticity of demand* (PE_D), and is measured as the ratio between the relative change of the demand and the relative price change, as shown in the following formula:

$$PE_D = \frac{\% \text{ change quantity demanded}}{\% \text{ change in price}}$$

3.1.2. Cost pass-through rate

One relevant route attribute for the choice described above is the airfare: this could be influenced because the EU ETS could lead to an increase in operational costs for the aviation sector, as airlines will have to buy allowances or invest in new technologies to reduce emissions. The *cost pass-through rate* refers to the degree to which these costs are passed on to customers. If this *potential cost price increase* is passed through to customers, this will lower demand. This reduction in demand can be considered an *intended effect* of climate policy, as it contributes to a reduction of emissions, and is not taken into account in this study as described above. In addition, if the *potential cost price increase* is passed through to customers this could lead to the redistribution of passengers to other airports like Dubai. On the other hand, if companies cannot pass through these costs because of the competition from non-EU carriers, this will lead to lower profit margins, resulting in *unintended effects* like a loss in competitiveness (Davidson et al., 2008). Figure 3.3 below shows the chosen approach on cost pass-through, and the relation between these cost effects:

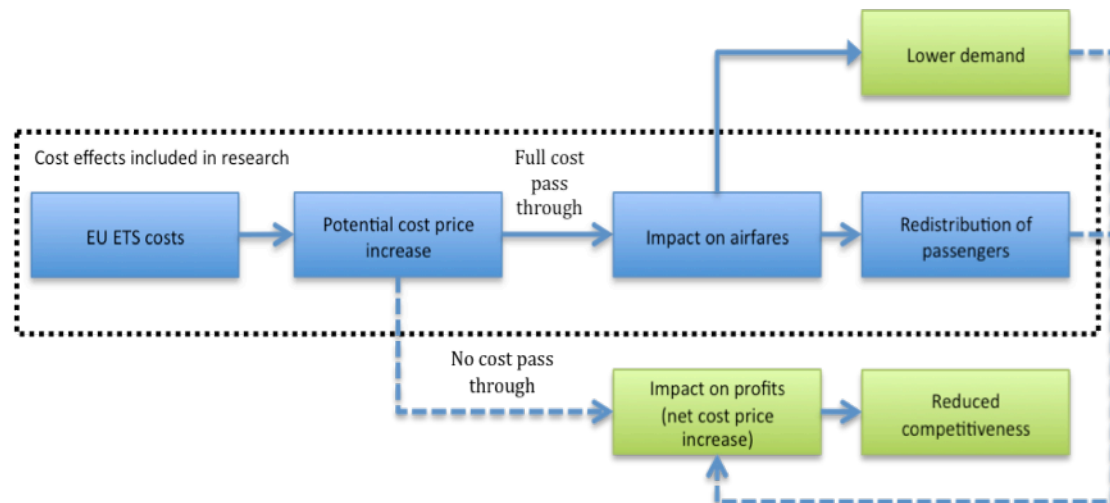


Figure 3.3: cost effects assumed in research (adapted from Davidson et al., 2008)

In this figure, the blue rectangles represent the cost effects taken into account in this study. The green rectangles represent effects not taken into account. As can be seen, for the purpose of this study it is assumed that these costs will be fully passed through, because

only in this way it is possible to gain full insight in possible redistribution effects⁶. In addition, based on current profit margins in the aviation sector it seems unlikely airlines can incur all EU ETS costs themselves. This is further substantiated in section 8.1. Thus, it is assumed that the net cost price increase for airlines is zero.

Box 3.2: Theory on cost pass through

When comparing reports on cost pass through like those by Davidson et al. (2008), Merrill Lynch (2008) and Ernst & Young (2007) it appears that the main factor determining whether these costs are expected to be fully passed through is the way airlines set their prices. In a well functioning market, where price setting is based on marginal costs, it is rational to pass through the opportunity costs of allowances. The resulting loss of demand (depending on the price elasticity of demand) could be borne by reducing the scale of operation in order to maintain profit margins (Boon et al., 2007).

Alternatively, in a capacity constrained market limited cost pass through can be expected: in such a market there is no full competition and therefore prices do not reflect marginal costs. Instead, the product price is set at the level that clears the demand at the given supply. Thus the clearing price is higher than the marginal costs of production at the given supply, and the difference is the *scarcity rent*. Similarly, if the specific market is characterized by a duopoly or oligopoly, only a very limited share of the costs can be expected to be passed through to consumers (Beimann, 2007) because the price is not determined by the marginal costs.

3.1.3. Cross-subsidisation

Cross-subsidisation could occur if carriers operating outside Europe allocate EU ETS costs to their non-EU markets, in order to reduce fares in Europe and gain market share at the expense of European carriers. In this research it is assumed that no additional cross-subsidisation will occur as a result of the inclusion of aviation in the EU ETS⁷: the EU ETS is no new incentive for such cross-subsidisation, and opportunities to raise fares in other markets are limited (Davidson et al., 2008).

3.2. Discrete choice model

The choice described in the previous section can be considered a *discrete choice*: individuals have to select an option from a finite set of alternatives. It is generally assumed that this can best be modelled with a *disaggregate demand model*, which is based on observed choices made by individual travellers. This type of model has been chosen, because it can be

⁶ Under the opposite assumption of no cost pass through, the developed model would show no impact of the EU ETS, as it only takes into account redistribution effects, and not the impact on overall demand or the profit margins of airlines.

⁷ Indirect cross subsidisation could occur, for example if non-European airlines use their cleanest aircraft on European routes and deploy their older, more polluting airplanes on other routes (Beimann, 2007). It is assumed this will have no significant effect, and is therefore not taken into account. This assumption is taken into account in chapter 8.

expected to result in a more realistic model compared with *aggregate demand models*, which are based on observed relations of groups of travellers, or on average relations at a zonal level (De D. Ortuzar and Willumsen, 1994).

It should be noted that the passenger route choice cannot be adequately modelled by ‘all or nothing’ models that assume all passengers simply choose the cheapest route: this choice depends on a combination of fare and many other *attributes* that together make up the quality of each alternative route option. From a modelling point of view, not all these attributes are known, and of those that are known not all are measurable. Therefore, to deal with this lack of information in this research a probabilistic model has been used (Alamdari and Black, 1992). This probabilistic model exists of a deterministic and a stochastic component. Both components are described in the next sections.

3.2.1. Deterministic component

In general, discrete choice models postulate that (De D. Ortuzar and Willumsen, 1994):

“The probability of individuals choosing a given option is a function of their socioeconomic characteristics and the relative attractiveness of the option”

This attractiveness of alternatives is represented by the concept of *utility*⁸. Accordingly, for this research a *utility-based discrete choice model* has been used, which postulates, in accordance with neoclassical economics (Chorus, 2009):

- 1) An alternative can be described as a *set of attributes* (e.g. travel time, airfare and number of stopovers)
- 2) Travellers choose the alternative with the highest utility

Using the Lancasterian utility theory, in this study it is assumed that the utility is a *linear additive function* of these attributes and the parameters (coefficients) that represent the preferences of passengers (Chorus, 2009).

Thus, the observed utility of a route alternative can for example be defined as the following linear combination of variables:

$$V_A = \beta_{current} + \beta_{fare} \times fare_a + \beta_{flight_time} \times flight_time_a$$

Where

V_A is the *observed utility* of route alternative A.

$\beta_{current}$ is the *alternative-specific constant (ASC)*: this represents the net influence of all unobserved or not explicitly included characteristics of an alternative. In this research the ASC refers to the difference in attractiveness between Dubai and Schiphol as a result of non-observed characteristics. For example, these could include characteristics that make Schiphol more attractive for travellers, like multi-lingual personnel or a large vat-free shopping zone.

⁸ Many studies in the field of transport (e.g. MVA Consultancy, 2006) use the concept of *generalized costs* instead of utility. This is a comparable concept, so in this study only the concept of utility has been used.

β_{fare} and β_{flight_time} are *coefficients* that give the relative influence (or *weight*) of each attribute like fare and flight time. Put differently, they capture the (dis)utility associated with an increase by one unit (1 minute or €1) in fare or flight time (Hess, 2008).

$fare_a$ and $flight_time_a$ are *attributes* of route alternative A, and in this case refer to the airfare and the flight time of alternative A.

3.2.2. Stochastic component

As described in the beginning of this section, it is impossible to determine the individual utility of each alternative for each traveller flawlessly, which is why an *error term* is always included. Thus, U_a (the net utility U of alternative a) = V_a (the observed utility) + ε (the error term). This error term is usually *extreme value type-I* or *Gumbel* distributed. By using a *Multinomial Logit Model (MNL)*, an error term drawn from this distribution is automatically included in the function (De D. Ortuzar and Willumsen, 1994).

3.3. Multinomial Logit function

To predict what share of individuals will choose a certain alternative, the value of its utility must be contrasted with those of other alternatives and transformed into a probability value between 0 and 1. This will represent the chance that an individual will choose this alternative. To derive this probability value several mathematical transformations exist, but as described in the previous paragraph using a MNL model is most suitable since it takes into account the error term. Since a choice between two options is modelled, a *binary logit model* is used in this study (De D. Ortuzar and Willumsen, 1994):

$$P_a = \frac{\exp(V_a)}{\exp(V_a) + \exp(V_b)}$$

Where

P_a is the probability that alternative A is chosen.

V_a is the observed utility of alternative A.

This probability equals the share of all individuals that will choose alternative A. To illustrate this formula, the exemplary curve in figure 3.4 on the next page shows the share of passengers choosing alternative A as a function of $V_b - V_a$.

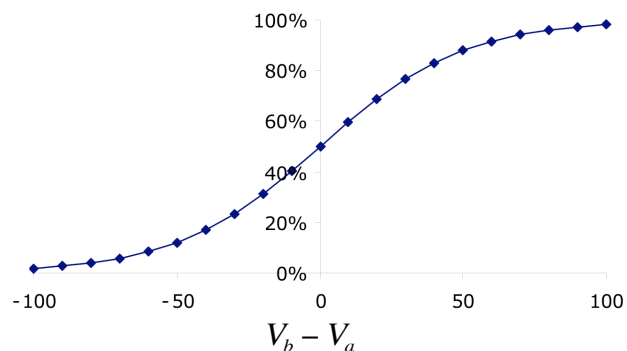


Figure 3.4: exemplary curve showing share of passengers choosing alternative A (taken from MVA Consultancy, 2006)

3.4. Passenger preferences

As described in the previous section, by using a MNL model an error term is implicitly included, thereby compensating for measurement errors and attributes that are not known or deliberately left out of the model. This makes it possible to select only a limited set of attributes. In this section it is explained how relevant attributes has been selected, and how values for these attributes have been acquired from another study that closely resembles the case of this research. The use of data from another study, which has been acquired in a different setting and airport implies two crucial assumptions (De D. Ortuzar and Willumsen, 1994):

1. Constants from the other study have been ignored, thereby implicitly assuming the ASC is equal (both airports are equal in non-observed characteristics).
2. Coefficients from the other study have been used directly in this research, thereby explicitly assuming that the effects of attributes on the choice behaviour in the Schiphol setting is equal to that in the original study.

3.4.1. Identifying relevant attributes

Many studies have been performed to identify which *'level-of-service'* attributes influence passengers' choices. A study by Loo (Loo, 2008) focuses on passengers' airport choice in multi-airport regions (MARs) and identifies an extensive list of attributes, as shown in table 3.1 below:

Table 3.1: ‘Level-of-service’ attributes (adapted from Loo, 2008)

<i>Primary attributes</i>	<i>Flight characteristics</i>	<i>Airport characteristics</i>
Airfare	Flight frequency In-flight travel time Number of stops Transfer arrangements Congestion/punctuality Airlines Aircraft type	Airport access time Access cost Access mode Parking facilities Check-in facilities Lounge, restaurant and shopping facilities Transfer facilities Baggage, customs and immigration facilities Airport tax or passenger charge

For this research, only attributes that differ between Schiphol or Dubai have been taken into account: attributes of another origin or destination airport are not taken into account since passengers have already chosen this origin and destination. In addition, parameters like average schedule delay, frequency and airport/airline ranking are assumed to be identical for both route alternatives and therefore left out of the model. In this way, only the following three route attributes are relevant for determining the redistribution of passengers:

- Airfare (including EU ETS costs)
- Flight time
- Number of stopovers

In the next sections it is explained how the relative influence of each attribute has been determined, and how values of attributes are calculated in the developed model.

3.4.2. Determining relative influence of attributes

For this research data from an existing study have been used. In this section the choice of an appropriate study is elaborated. Since the focus of this research is on the discrete, binary choice between two route options, coefficients from a stated preferences study where two possible alternatives are presented to travellers are most suitable (Loo, 2008). Box 3.3 below describes the properties of stated preferences studies in more detail. When comparing existing studies, it should be noted that with the rise of the Internet, the way travellers choose their airline and route has drastically changed: instead of booking through a travel agent who presents a few possible options, travellers use the internet to compare all possible routes on criteria like price, travel time and number of stopovers⁹. As a result, older studies have little predictive values today. In addition, since the binary logit model formulated above is a *linear additive function*, only coefficients from studies using a linear logit model are compatible.

Based on these requirements, several appropriate studies have been identified: a study on air travel behaviour modelling by Hess (2007), a study on air travel choices by Ishii et al. (2009), a study on passenger’s airport choice by Loo (2008), and a study on airport and airline choice by Pels et al. (2001). After a thorough comparison, the study by Hess has been chosen because it provides exactly the coefficients needed and does not distinguish between different types of travellers (a distinction between leisure and business passengers

⁹ This increased transparency has driven airlines to use complex pricing mechanisms. This is described in section 8.1

is made in other studies), which would require another, more complex modelling approach. The table below gives an overview of these coefficients:

Table 3.2: overview of coefficients for route attributes (taken from Hess, 2007)

<i>Attribute</i>	<i>Coefficient</i>
Flight time [hrs ¹⁰]	-0.264
Airfare [€ ¹¹]	-0.0195
Number of stopovers [discrete]	-0.6608

Box 3.3: stated versus revealed preferences

When determining the preferences of individuals, often a distinction is made between *stated preferences* and *revealed preferences*. *Stated preferences* are determined by explicitly asking individuals *ex ante* what choices they would make: in the case of air travel, this could for example be in the form of a survey where respondents indicate what price they are willing to pay for a certain flight, or where they have to choose between two alternative flights as shown in Figure 3.5. *Revealed preferences* on the other hand are determined by analyzing the *actual* behaviour of individuals *ex post*, and deriving their preferences from this behaviour.

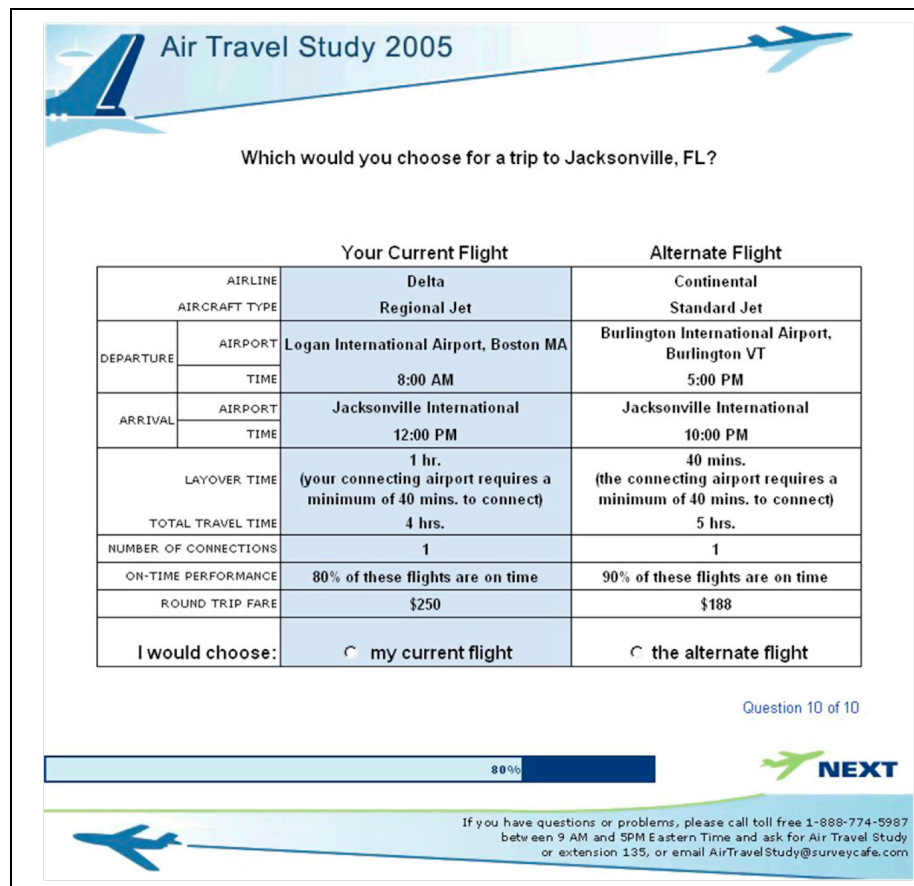


Figure 3.5: example screen-shot for Stated Preferences survey (taken from Hess, 2007)

¹⁰ converted from minutes

¹¹ converted from dollars

3.4.3. Validation of coefficients

To validate the coefficients acquired in the previous paragraph, the *ratios* between airfare and the other two coefficients have been calculated to express the 'value' of a coefficient: the value of time (VoT) is €13.54 per hour and the value of a stopover is €33.89 per stopover. These ratios indicate what price passengers are willing to pay for one hour less flight time or for a direct flight, based on the sample group analyzed in the stated preferences study by Hess. These ratios have been compared with several other studies that focus specifically on Schiphol passengers: MVA Consultancy uses a segmented approach and indicates a VoT of €20 for leisure passengers and €50 for business passengers (MVA Consultancy, 2006). Stratagem assumes a uniform VoT of €27.86 (Stratagem Strategic Research, 2004).

Regarding the value of a stopover, no other recent studies could be found. Therefore an older study by Kanafani et al. has been used to determine the value of a direct flight in terms of time: it shows a direct flight is worth 1.74 hours of flight time (Kanafani and Ghobrial, 1985), versus 2.50 in the study of Hess. Thus, it can be concluded that the ratios in Hess' study seems plausible for leisure passengers. However, the VoT for business passengers is considerably higher, which would result in a lower sensitivity to cost differences caused by the EU ETS (Alamdari and Black, 1992). This is addressed in chapter 8.1. In addition, it should be noted that the coefficient for the number of stopovers includes the extra travel time involved: as shown, a stopover equals 2.5 hours of travel. This is comparable to the assumptions made by MVA Consultancy (2006) that suggest a stopover equals 1 hour of travel time, multiplied by an 'inconvenience penalty' between 2 and 3.

3.4.4. Application of coefficients

Based on these coefficients, the following formula can be derived to describe the observed utility of a given alternative:

$$V_A = -0,264 \times fare_a - 0,0195 \times flight_time_a - 0,6608 \times stopovers_a$$

Using the calculated observed utility of both alternatives, the probability of passengers choosing one alternative (including the error term) is then calculated by the binary logit model provided earlier in this chapter:

$$P_a = \frac{\exp(V_a)}{\exp(V_a) + \exp(V_b)}$$

3.4.5. Conclusion of chapter

In this chapter a model has been developed that allows for the calculation of the probability of route alternatives as a function of passenger preferences and attributes of the route alternatives. To this end, the values of coefficients representing passenger preferences have been acquired from another study. To implement the model for the case studied in this thesis, in the next chapter it is described how the attributes for all route alternatives have been determined.

4. Model implementation

As described in the previous section, an air traveller selects a route based on his *socioeconomic characteristics* and the *relative attractiveness of the option*. In this chapter the choice for Dubai as indicator of the possible impact of the EU ETS is explained. Then, attributes of routes via Schiphol and possible alternatives via Dubai are determined, in order to calculate the relative attractiveness of Schiphol versus Dubai for each market segment.

4.1. Gulf hubs

Although various hubs around the world are potential competitors of Schiphol on the intercontinental transfer market, the hubs located in the Arabian Gulf region seem most likely to benefit from the EU ETS to gain market share at the expense of Schiphol. First of all, they are perfectly positioned for traffic between Europe's Northern Hemisphere and Asia's Southern Hemisphere. Secondly they focus mainly on intercontinental transfer passengers, a very important market segment for Schiphol. Thirdly, they are investing large amounts of money to expand their capacity. Based on these characteristics, O'Connell (2006) identifies three 'global challengers': Emirates, Qatar and Etihad airlines, the main carriers of Dubai, Qatar and the United Arab Emirates (UAE) respectively. The figure on the right shows the location of those countries, while figure 4.2 below shows the long-haul capacity on order in the Gulf region versus Europe and Asia Pacific. Recent figures by the IATA confirm the growth potential of these carriers, as they were able to realize 9.5% growth in 2009, while other airlines around the world faced a traffic reduction of around 10% as a result of the current economic crisis (IATA, 2009a).



Figure 4.1: location of Gulf states (taken from O'Connell, 2006)

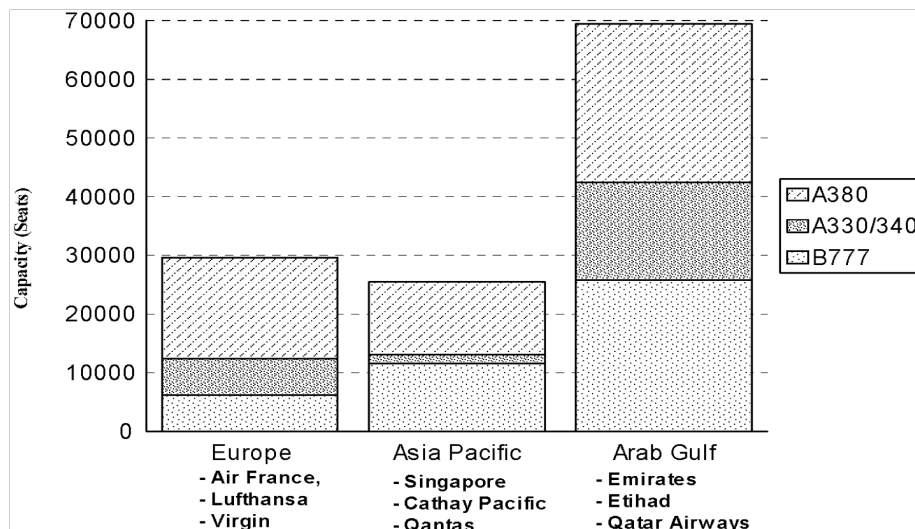


Figure 4.2: long-haul capacity on order in 2005 (taken from O'Connell, 2006)

4.2. Dubai airport

In this thesis the focus is on Dubai airport only, as it has the largest capacity of all three Gulf carriers, and the most extensive investment plans: 7.1 billion euro has been reserved to extend Jebel Ali International Airport and make it larger than the world's current two largest airports combined. It should be able to accommodate 120 million passengers annually, four times as much as Schiphol at this moment. To this end its home carrier Emirates Airlines has ordered 42 Boeing 777s and 43 Airbus A380s to expand its fleet. The only way to utilize this huge capacity is by flying on large intercontinental routes, since Dubai itself has only 1.7 million inhabitants (O'Connell, 2006).

4.3. Taxonomy of market segments

In this study passenger flows have been researched on an aggregated level because a dataset with flight schedules and origin-destination-tables for all possible routes is not publicly available. Therefore for this research the concept of *market segments* is used: a market segment can be defined as a "subgroup of people or organizations sharing one or more characteristics that cause them to have similar product needs" (Hutchinson, 2009).

In this research, a market segment represents a subgroup of all passengers at Schiphol that has an equal origin and destination region.¹²

As shown by Vespermann et al. (2008), Middle Eastern carriers like Emirates focus mainly on three major market segments: traffic between Europe and Asia, between North America and Asia and between North America and Europe. In addition, these three regions are most

¹² It should be noted that in this context the term market segment has nothing to do with marketing or the targeting of certain groups of customers.

important for Schiphol in terms of passenger numbers and profitability (Van den Berg, 2009). Therefore only the following regions have been included in the model:

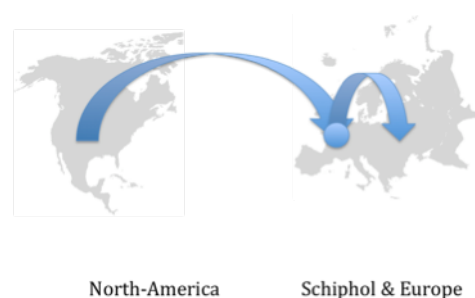
- North America
- Asia (including Middle East)
- Europe (all countries on the European continent that are taking part in the EU ETS)

In addition, an important distinction must be made between transfer and direct passengers at Schiphol: direct passengers have their final origin or destination at Schiphol, while transfer passengers are only using Schiphol as a hub between two connecting flights¹³. Thus, the following seven market segments have been distinguished, for which the corresponding shares of passengers have been obtained in interviews and by using several publicly available reports.

1) Transfer N. America – Asia: this refers to passengers who undertake a trip existing of two intercontinental (ICA) flights between North America and Asia, with a stopover in Schiphol. Examples are New York – Schiphol – Shanghai or Mumbai-Schiphol-Toronto.



2) Transfer N. America – EU: this refers to passengers who travel between North America and Europe, with a stopover in Schiphol. Examples are New York – Schiphol – Stockholm and Rome – Schiphol– Los Angeles.



3) Transfer Asia – EU: this refers to passengers travelling between Asia and Europe, with a stopover in Schiphol. Examples are Shanghai – Schiphol – Stockholm and Rome – Schiphol – Mumbai.

¹³ In practice, transfer passengers could undertake a trip existing of more than two flights, for example with a stopover in North America and one at Schiphol. However, since these extra stopovers will remain when flying through Dubai instead of Schiphol, they are not taken into account.



Schiphol & Europe

Asia & Middle East

4) Transfer EU – EU¹⁴: this refers to passengers flying intra-European flights with a stopover in Schiphol, like London – Schiphol – Stockholm.



Schiphol & Europe

5) Direct Schiphol – N.America: This refers to passengers flying directly between Schiphol and North America, for example Schiphol – New York.



North-America

Schiphol

6) Direct Schiphol – Asia: This refers to passengers flying directly between Schiphol and Asia, for example Schiphol – Shanghai.



Schiphol

Asia & Middle East

7) Direct Schiphol – Europe¹⁵: This refers to passengers flying directly between Schiphol and a European destination, for example Schiphol – London.



Schiphol & Europe

An important remark needs to be made with regards to these market segments:

Direct passengers (market segment 5,6 or 7) who choose to fly through Dubai, will still depart from or arrive at Schiphol since they have their final origin or destination there. Therefore a redistribution in these market segments will not lead to a decrease in the number of passengers at Schiphol. However, this switch could still have an impact on the network quality, as those passengers all fly through Dubai instead of directly to their destination. Also this could affect Schiphol indirectly as it could affect carriers using Schiphol as their hub, since they will lose passengers to Dubai carriers. This has been addressed in the reflection in chapter 11.

4.4. Overlap of market segments

In this section it is explained how the overlap between Schiphol and Dubai in each of the seven market segments defined above has been determined.

Carriers at Dubai focus mainly on the eastern hemisphere, while Schiphol's main markets are Europe and North America, both in terms of passenger numbers and in terms of profitability (Vespermann et al., 2008, Van den Berg, 2009). As a result, there is currently a limited degree of destination overlap between Schiphol and Dubai as shown by a study by Kolkman and Korteweg (2009)(Kolkman and Korteweg, 2009): the figure below is based on data from this study and shows the actual overlap of destinations between Schiphol and Dubai per region: it displays the number of destinations per region served from Schiphol (blue), the number of destinations served from Schiphol and Dubai (red) and the number of destinations served solely from Dubai (green):

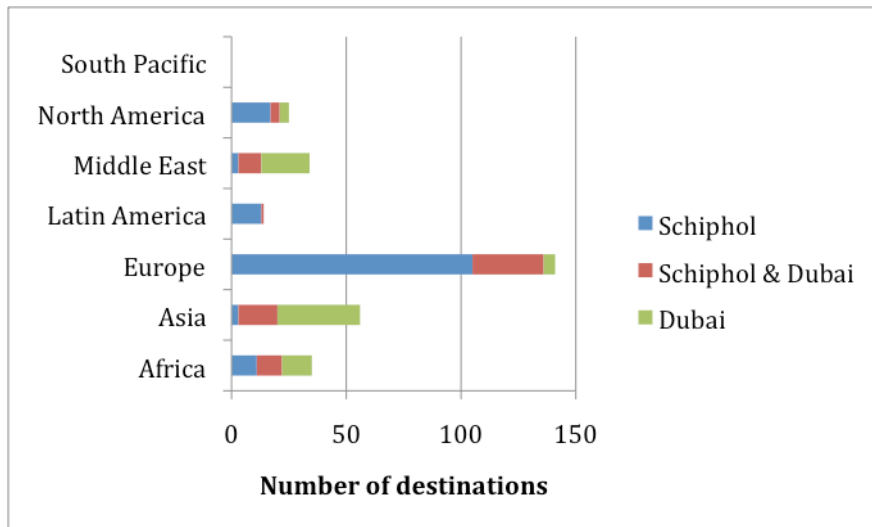


Figure 4.3: overlap of destinations Schiphol and Dubai (based on Kolkman and Korteweg, 2009)

For this research, it has been assumed that the overlap in market segments can be directly derived from this overlap in destinations. To clarify this assumption, an exemplary calculation is shown below:

Destinations in N.America served from Schiphol only = 17

Destinations in N.America served from Schiphol and Dubai = 4

Thus, the overlap between Schiphol and Dubai in N.America = $4 / (4+17) = 19,0\%$

In a similar way the overlap for Europe and Asia has been calculated. For the first market segment (passengers between North America and Asia with a stopover at Schiphol), it is assumed that the region with the lowest destination overlap determines the total overlap: in this segment this proves to be North America. Based in the data on destination overlap provided in appendix II, the following table has been compiled:

Table 4.1: initial overlap per market segment

<i>Market segment</i>	<i>Overlap</i>
1) Transfer N. America - Asia	19.0%
2) Transfer N. America - EU	19.0%
3) Transfer Asia - EU	22.8%
4) Transfer EU - EU	22.8%
5) Direct Schiphol – N. America	19.0%
6) Direct Schiphol – Asia	81.8%
7) Direct Schiphol - EU	22.8%

It should be noted that due to the aforementioned planned investments in Dubai airport and Emirates airlines it can be assumed that this overlap will increase during the evaluated period. Table 4.2 on the next page supports this presumption, as it shows Emirates plans to expand its destinations each year:

Table 4.2: Emirates planned new destinations (taken from Horth and Alwyn, 2005)

2005	Seoul	Cape Town	Hamburg	Geneva	Seychelles
2006	Prague	Antananarivo	Taipei		
2007	Amsterdam	Copenhagen	Bangalore	Beijing	Toronto
	Lusaka	Windhoek			
2008	Chicago	Los Angeles	Washington DC		
2009	Boston	Kano	Vancouver	Kinshasa	Dublin
2010	Warsaw	Freetown	Tokyo		
2012	Houston				

Based on the initial overlap as shown in table 4.1, the future overlap between Schiphol and Dubai has been calculated by using the following formula:

$$O_{x+n} = (O_x * (1 + G))^n$$

where

O_{x+n} = overlap between Schiphol and Dubai n years after initial overlap

O_x = initial overlap between Schiphol and Dubai

G = annual growth of network of Dubai

n = number of years since base year

This formula has been applied in chapter 5 to calculate the network overlap under several scenarios where the annual growth of the network of Dubai is varied.

4.5. Share of market segments

To determine the share of each market segment at Schiphol, data from several sources have been combined. In this section an overview of relevant data is provided, as presented in the interviews and found in annual reports.

Table 4.3: shares of passenger types

<i>Type of passengers</i>	<i>Share of all passengers at Schiphol¹⁶</i>
Local/direct (O&D)	59%
Transfer	41%
<i>Destination</i>	<i>Share of all passengers at Schiphol¹⁷</i>
European	68%
Intercontinental	32%

¹⁶ (Schiphol Group, 2007c)

¹⁷ Ibid

Table 4.4: shares of market segments

<i>Market segment</i>	<i>Share of all passengers at Schiphol¹⁸</i>
1) Transfer N. America - Asia	5.0%
2) Transfer N. America - EU	4.8%
3) Transfer Asia - EU	5.9%
4) Transfer EU - EU	30.0%
5) Direct Schiphol – N.America	5.4%
6) Direct Schiphol – Asia	6.6%
7) Direct Schiphol - EU	33.0%
<i>Other passengers (not included in model)</i>	<i>9.3%</i>

4.6. Attributes of market segments

For each market segment, attributes for the ‘average’ route through Schiphol and an alternative route via Dubai have been determined. To this end, the average flight time and average airfare have been calculated by identifying the top ten routes for each market segment in terms of passenger numbers, and then determining a weighted average distance for each segment. This is elaborated in the following sections. After that, it is explained how the number of stopovers for each segment has been determined.

4.6.1. Weighted average distance

‘Weighted’ average distances have been estimated by calculating the average distance of the *great circle distances* of the most popular destinations for each market segment and assigning a weight that depends on the annual number of passengers¹⁹. A detailed explanation of this calculation can be found in appendix III, while a definition of the great circle distance is given in the box below. In this way, weighted average distances have been estimated for both route alternatives in each market segment.

Box 4.1: great circle distance

The **great circle distance** or **orthodromic distance** is the shortest path between two points on a globe. Many internet sites provide tools to calculate this distance between two locations (Frasssek, 2009). Mathematically this distance is given by

$$d = r \Delta \hat{\sigma}.$$

$$\Delta \hat{\sigma} = 2 \arcsin \left(\sqrt{\sin^2 \left(\frac{\Delta \phi}{2} \right) + \cos \phi_s \cos \phi_f \sin^2 \left(\frac{\Delta \lambda}{2} \right)} \right)$$

where

$\phi_s, \lambda_s; \phi_f, \lambda_f$ are the geographical latitude and longitude of two points
 $\Delta \phi, \Delta \lambda$ their differences
 $\Delta \hat{\sigma}$ the (spherical) angular difference/distance

¹⁸ (Van Unnik, 2009)

¹⁹ It should be noted that this analysis has been performed by selecting the most popular routes measured by number of passengers at Schiphol, since the aim of this analysis is to measure the impact at Schiphol. This explains why average distances are higher for Dubai.

Table 4.5: weighted average distances

<i>Market segment</i>	<i>Weighted average distance via Schiphol [km]</i>	<i>Weighted average distance via Dubai [km]</i>
1) Transfer N. America - Asia	15299	17160
2) Transfer N. America - EU	7425	16714
3) Transfer Asia - EU	9542	10625
4) Transfer EU - EU	1688	10179
5) Direct Schiphol – N. America	6592	16797
6) Direct Schiphol – Asia	8708	10709
7) Direct Schiphol - EU	834	10262

In addition, for each market segment and the alternative routing via Dubai it has been determined to what extent the flights fall under the EU ETS: since airlines only need to acquire allowances for flights arriving or departing in Europe, intercontinental flights to and from outside Europe to Dubai do not need to obtain allowances (even if a substantial share of the passengers has its final origin or destination in Europe). For example, for a route like New York-Dubai-Mumbai no allowances are needed at all, since both flights do not arrive or depart at a European airport²⁰. In contrast, for a route like Shanghai-Dubai-London allowances are needed for the second leg of the flight. In such a case the weighted average distance between Dubai and major European destinations has been used for calculation.

Table 4.6: weighted average distances under EU ETS

<i>Market segment</i>	<i>Avg. distance under ETS via Schiphol [km]</i>	<i>Avg. distance under ETS via Dubai [km]²¹</i>
1) Transfer N. America - Asia	15299	0
2) Transfer N. America - EU	7425	5089
3) Transfer Asia – EU	9542	5089
4) Transfer EU - EU	1668	10179
5) Direct Schiphol – N. America	6592	5173
6) Direct Schiphol – Asia	8708	5173
7) Direct Schiphol - EU	834	10262

4.6.2. Weighted average flight time

In this study it has been assumed that the average flight time for a market segment is proportional to the average distance: from the weighted average distances the average flight times have been calculated by dividing the distance by the average aircraft cruise speed, which is approximately 900 km/hr. Additional time factors have not been taken into account because they are assumed equal for Schiphol and Dubai, for example the time

²⁰ In fact the flight between New York and Dubai will cross European airspace, but according to the EU directive for such flights no allowances are required.

²¹ Weighted average distance between Dubai and Europe's main destination, or distance between Dubai and Schiphol

required for taxiing, take-off and landing. Stopover time is not included in the analysis either, since this is already included in the negative utility coefficient associated with it (as described in section 3.4.3). In this way, the following average flight times have been calculated:

Table 4.7: average flight times (excl. airport/stopover time)

<i>Market segment</i>	<i>Average flight time via Schiphol [hrs]</i>	<i>Average flight time via Dubai [hrs]</i>
1) Transfer N. America - Asia	17.0	19.1
2) Transfer N. America - EU	8.3	18.6
3) Transfer Asia - EU	10.6	11.8
4) Transfer EU - EU	1.9	11.3
5) Direct Schiphol – N. America	7.3	18.7
6) Direct Schiphol – Asia	9.7	11.4
7) Direct Schiphol – EU	0.9	11.4

4.6.3. Weighted average airfare

In this study it has been assumed that there is a linear relationship between the distance of a route and the airfare (this has been elaborated in section 8.1). It is assumed that the airfare consists of the average ticket price plus the costs incurred by the EU ETS.

Ticket price

With regard to the ticket price, it is assumed that airlines charge an equal price for a certain market segment, even if one route alternative spans a longer distance. The average ticket price per kilometre has been used as an indicator of this price. This factor is provided in the annual report of carriers as the Unit Revenue per RPK (Revenue Passenger Kilometre). This equals the total revenue divided by the RPK, and thus the revenue per kilometre a passenger has flown. Since the main source of income for airlines is the sale of tickets, this will approximate the ticket price per kilometre. For this study KLM's annual report has been analyzed since it is Schiphol's main carrier. A calculation factor of 0.0875 €/km has been found²². Based on this calculation factor, the following average ticket prices have been used in the model:

²² To verify this relation between distance and airfare, the average airfare on one of the most heavily travelled international routes, New York – London, has been calculated: with an average fare of €500 in 2004 (Bowen, 2004) and a distance of 5579 kilometres, the calculation factor is 0.0896 €/km. This confirms the findings above. Furthermore, it will be assumed Emirates will use the same tariffs as European carriers to gain market share, even though on some routes their actual costs could be higher.

Table 4.8: weighted average ticket price

<i>Market segment</i>	<i>Average ticket price [€]</i>
1) Transfer N. America - Asia	1339
2) Transfer N. America - EU	650
3) Transfer Asia - EU	835
4) Transfer EU - EU	146
5) Direct Schiphol – N. America	577
6) Direct Schiphol – Asia	762
7) Direct Schiphol – EU	73

EU ETS costs

The costs incurred as a result of the EU ETS are a function of the allowance price and the emissions per passenger. In this model the CO₂ price is considered an exogenous input that is varied between scenarios. The emissions per passenger are a function of several *input variables* like distance and average fuel use. To determine the emissions per passenger, for this thesis the methodology as shown in figure 4.4 below has been developed:

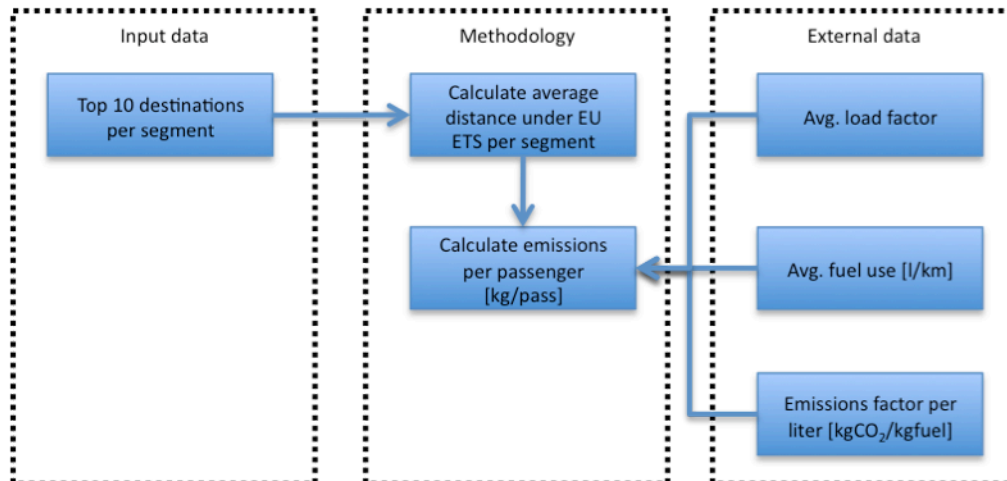


Figure 4.4: methodology to determine emissions per passenger (based on Jardine, 2009)

In appendix IV the calculation of EU ETS costs is elaborated in more detail.

4.6.1. Number of stopovers

As described in section 4.3, only a possible stopover at Schiphol or Dubai is taken into account, as other stopovers will be equal for both route alternatives and will therefore not differentiate between those alternatives. As a result, all transfer passengers incur one stopover while direct passengers only incur a stopover when travelling through Dubai (instead of directly from Schiphol to their destination).

4.7. Input variables

To implement the model, a large number of variables have been quantified, in addition to the route properties in section 4.4 and 4.6. To this end, a distinction has been made between two types of input variables: *static input variables* and *scenario specific input variables*: static input variables are constant in all scenarios and relate to flight and sector characteristics. Scenario specific input variables, on the other hand, are varied between scenarios and relate to policy, technical and economical aspects. Values for both categories have been acquired from other studies, interviews, calculations and estimations. An overview of all input variables is provided in the tables below. A more detailed overview of static input variables is given in appendix V. Furthermore, in the next section scenario-specific input variables have been specified in more detail.

Table 4.9: static input variables

<i>Flight characteristics</i>	<i>Sector characteristics</i>
➤ Fuel use	➤ Avg. sectoral emissions 2004-2006
➤ Emissions factor per kg	➤ Relative emissions cap in 2012
➤ Density of kerosene	➤ Aviation cap 2012
➤ Emissions factor per litre	➤ Sectoral emissions 2012
➤ Assumed aircraft capacity	➤ Unit revenue per RPK
➤ Average load factor	➤ Total passengers transported at Schiphol in 2008
➤ Average load	➤ Total emissions in the Netherlands
➤ Emissions per passenger per km	
➤ Average aircraft speed	

Table 4.10: scenario-specific input variables

<i>Policy variables</i>	<i>Technical variables</i>	<i>Economical variables</i>
➤ Aviation auctioning share	➤ Annual sector efficiency increase	➤ Annual aviation growth
➤ Annual reduction of aviation emissions cap		➤ CO ₂ allowance market price
		➤ Annual growth of destinations from Dubai

5. Scenario development

Scenarios provides a way to deal with the inherent uncertainty on several key values, for example the development of the carbon market or the growth rate of Dubai. By developing several scenarios that incorporate the possible range of those key values, one can gain insight in the possible range of outcomes. In this research, the main research objective is to identify the effect of the EU ETS on the redistribution of passengers between Schiphol and Dubai. To this end a 'reference' distribution is calculated by calibrating the model to the assumed conditions in 2012, just before the inclusion of aviation in the EU ETS. Then, by developing several 'null'-scenarios for the expected conditions in 2020 in which the attributes of route alternatives are varied, it is possible to see the redistribution of passengers without EU ETS costs (for example because the allowance price falls to zero). Subsequently, by developing similar scenarios where EU ETS costs are introduced, it is then possible to compare the redistribution of passengers between scenarios with and without EU ETS. Figure 5.1 illustrates this with an exemplary case of two scenarios:

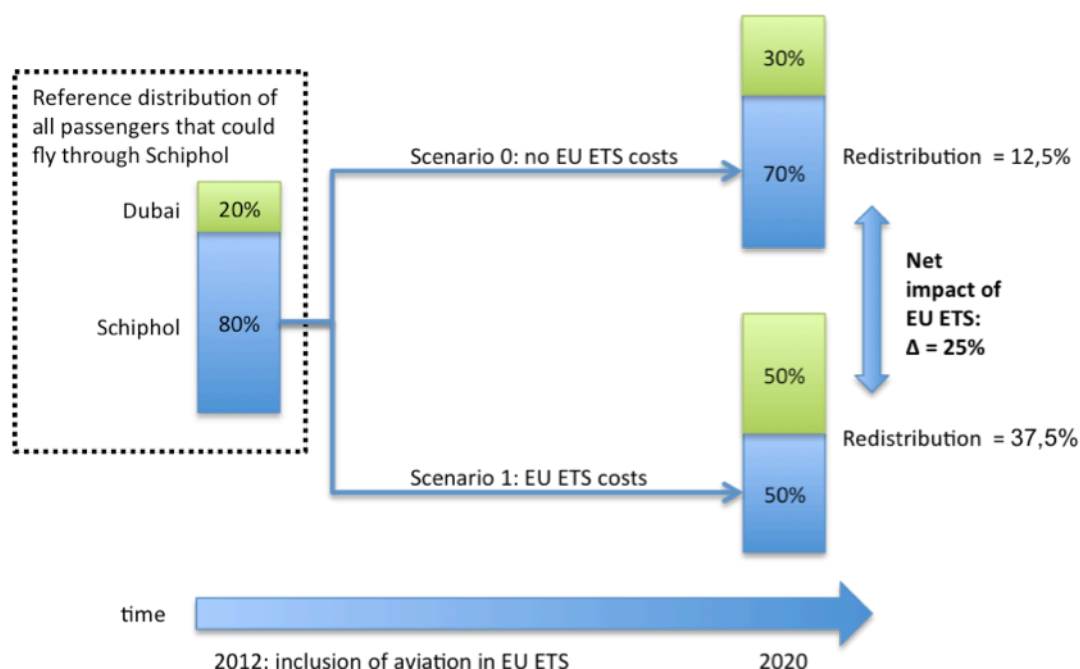


Figure 5.1: exemplary distribution of passengers in reference situation and two scenarios

As shown, the redistribution differential between scenarios gives a clear indication of the redistribution effects of the EU ETS. To place these outcomes in a broader context several other developments have been taken into account in these scenarios as well. The following section will elaborate on the scenario development and the main outcomes of each scenario.

5.1. Scenario-specific input variables

Hypothetically, the scenario-specific input variables identified in the previous chapter provide for an infinite amount of possible scenarios. To develop a limited number of

consistent scenarios the following three *driving forces* that are the main drivers behind those variables have been used:

- Economic growth
- Growth of Dubai
- Development of climate policy

An overview of these *driving forces* is shown in the scenario axis in figure 5.2 below:

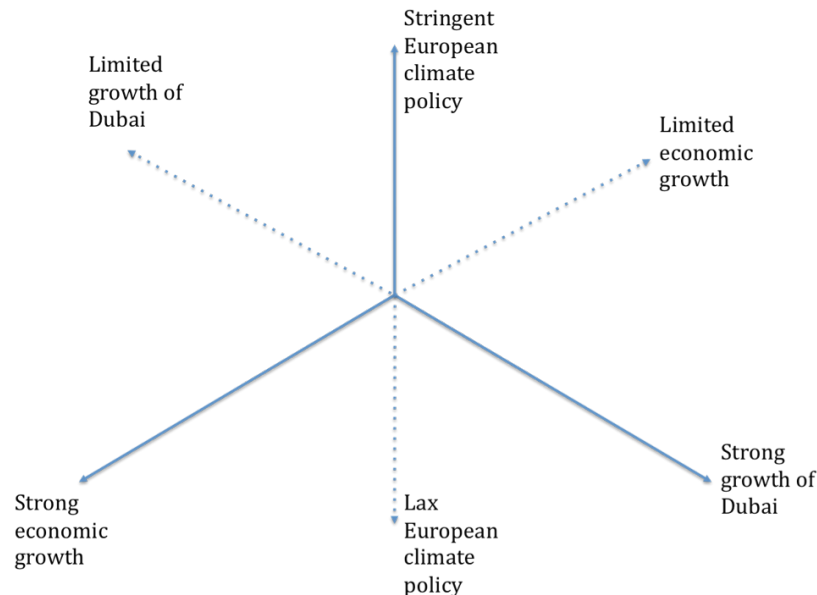


Figure 5.2: axis with driving forces for scenario development

Each driving force influences one or several input-specific variables in a similar way, as shown in the table below: for example, high economic growth is assumed to lead to a high allowance market price and high annual aviation growth. Based on the properties of the variables as described in appendix VI, the following values were chosen:

Table 5.1: overview of driving forces and variables

<i>Driving force</i>	<i>Influenced variables</i>	<i>Low value</i>	<i>High value</i>
Economic growth	CO ₂ allowance market price	30	60
	Annual aviation growth	5 %	7.5 %
Growth of Dubai	Annual growth of destinations from Dubai	2 %	5%
	Aviation auctioning share	15%	30%
European climate policy	Annual reduction of aviation emissions cap	0%	1.74%
	Annual sector efficiency increase	-1%	-2%

To number these scenarios in a clear way, the following scenario logic has been used:

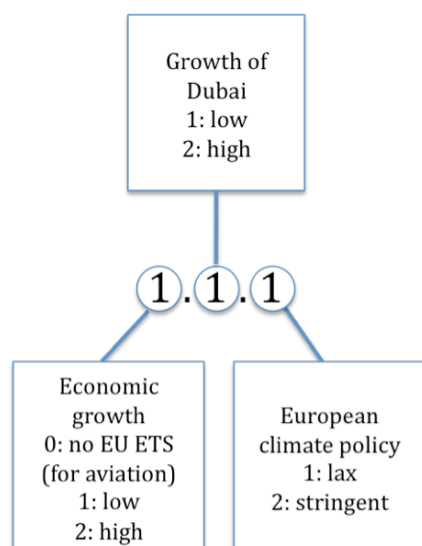


Figure 5.3: scenario logic

In this way, each scenario number can easily be translated to the underlying values for driving forces. In the following section, the model is first calibrated to the assumed starting conditions. Then each scenario is described in more detail

5.2. Overview of scenarios

Using the scenario logic described above, six²³ scenarios have been developed in which EU ETS costs are assumed. As described in the introduction of this chapter, these scenarios serve first and foremost to show the impact of the EU ETS. Therefore, two additional ‘null’-scenarios have been developed in which the EU ETS has no cost effect. By developing several scenarios where all conditions are equal and only the EU ETS related variables are adjusted, one can gain a quantitative insight in the share of passengers switching to Dubai as a result of the EU ETS, compared with the share of passengers switching due to other reasons (for example the growth of the network of Dubai). The developed scenarios have the following properties:

Scenario 0.1 and 0.2 (‘null’-scenarios): no EU ETS costs

Under these scenarios, it is assumed that the EU ETS has no cost effect on aviation. This could either be because it is decided aviation is not included in the EU ETS at all, because the allowance price drops to zero, or because the aviation sector receives all the required allowances for free (in case of 0% auctioning and a sufficient high aviation emissions cap). Therefore, the only relevant scenario-specific input variable is the annual growth of destinations from Dubai, which is set to 2% in 0.1 and to 5% in 0.2

²³ Although up to 8 scenarios could be developed in this way ($2^3=8$), for this research it has been assumed that a stringent climate policy is unlikely to emerge if there is limited economic growth, thus limiting the number of scenarios to six.

Scenario 1.1.1 and 1.2.1: limited EU ETS costs

Under these scenarios, limited EU ETS costs are introduced by assuming an allowance price of €30 per tCO₂. It is assumed that no changes are made to the EU ETS, so the aviation auctioning share is set to 15% and there is no annual reduction of the aviation emissions cap. The annual growth of the European aviation sector is assumed to be 5%, and the sectoral efficiency increase is set to 1% per year. Under 1.1.1, Dubai's network is set to grow by 2% per year, and in scenario 1.2.1 by 5% per year.

Scenario 2.1.1 and 2.1.2: high EU ETS costs, limited growth of Dubai

Under these scenarios, high EU ETS costs are introduced by assuming an allowance price of €60 per tCO₂. Furthermore, the growth of the network of Dubai is assumed limited at 2% per year. Under 2.1.1, no changes are assumed to the EU ETS, while in 2.1.2 it is assumed that the aviation cap will be reduced by 1.74% per annum. In addition, in 2.1.2 it is assumed that the European aviation sector will grow strongly by assuming a 7.5% annual growth and a 2% annual sectoral efficiency increase.

Scenario 2.2.1 and 2.2.2: high EU ETS costs, strong growth of Dubai

These scenarios are similar to 2.1.1 and 2.1.2, except for the strong growth of Dubai: a 5% annual growth of Dubai's network is assumed.

An overview of all scenario-specific input variables for each scenario is provided in table 5.2 below:

Table 5.2: overview of scenario-specific inputs for all scenarios

<i>Scenario</i>	<i>Aviation auctioning share</i>	<i>Annual reduction aviation cap</i>	<i>Annual sector efficiency increase</i>	<i>Annual aviation growth</i>	<i>Allowance market price</i>	<i>Annual destination growth Dubai</i>
Reference	0%	0%	0%	0%	0	0%
0.1	0%	0%	-1%	5%	0	2%
0.2	0%	0%	-1%	5%	0	5%
1.1.1	15%	0%	-1%	5%	30	2%
1.2.1	15%	0%	-1%	5%	30	5%
2.1.1	15%	0%	-1%	7.5%	60	2%
2.1.2	30%	-1.74%	-2%	7.5%	60	2%
2.2.1	15%	0%	-1%	7.5%	60	5%
2.2.2	30%	-1.74%	-2%	7.5%	60	5%

To measure the impact of the EU ETS, the redistribution in scenario 1.1.1., 2.1.1. and 2.1.2. is compared with null-scenario 0.1. Similarly, the redistribution under 1.2.1, 2.2.1 and 2.2.2 is compared with null-scenario 0.2.

5.3. Calibration of model to reference situation

By combining the data provided in the tables in this section with the coefficients for passenger preferences in the previous section, a MNL model has been compiled. This model has been calibrated to the expected equilibrium distribution of passengers between Schiphol and Dubai in 2012. Table 5.3 given an overview of the assumed starting conditions for scenario-specific variables:

Table 5.3: Value of scenario-specific variables in reference situation

<i>Input</i>	<i>Value</i>
Allowance market price	0
Aviation auctioning share	0%
Annual reduction of aviation emissions cap	N.A.
Annual aviation growth	N.A.
Autonomous efficiency increase	N.A.
Annual growth of destinations from Dubai	N.A.

Based on these values, table 5.4 below gives the initial distribution of passengers in the reference situation for each market segment. The column on the right represents the share of passengers that *would fly through Schiphol if Dubai were not available*. Thus, together these passengers represent the *total potential Schiphol passengers*.

Table 5.4: distribution for each market segment in reference situation

<i>Market segment</i>	<i>Schiphol</i>	<i>Dubai</i>
1) Transfer N. America - Asia	93.0%	7.0%
2) Transfer N. America - EU	98.8%	1.2%
3) Transfer Asia - EU	90.4%	9.6%
4) Transfer EU - EU	98.3%	1.7%
5) Direct Schiphol – N. America	99.5%	0.5%
6) Direct Schiphol – Asia	79.8%	20.2%
7) Direct Schiphol - EU	99.3%	0.7%

This distribution provides the reference for the scenarios used in this research: in this way the *relative change* of the projected distribution of passengers between Schiphol and Dubai in different scenarios can be calculated.

Part III – Outcomes of research

6. Model results

In this chapter the outcomes of the model under different scenarios are presented. First an overview of the total passenger redistribution under each scenario is given. Then the redistribution per market segment is shown. In the next chapter the outcomes are analyzed.

6.1. Impact on all passengers at Schiphol

The table below gives an overview of the projected redistribution of passengers during phase III of the EU ETS in each scenario. As indicated earlier, these percentages indicate what share of all passengers flying through Schiphol in the reference situation switch to Dubai in the specific scenario. No insight is provided in demand effects of the EU ETS, as described in section 3.1.1.

Table 6.1: projected redistribution of all passengers at Schiphol in different scenarios

<i>Scenario</i>	<i>Total redistribution of passengers</i>
0.1	-0.27%
0.2	-0.76%
1.1.1	-0.33%
1.2.1	-0.83%
2.1.1	-0.43%
2.1.2	-0.44%
2.2.1	-0.95%
2.2.2	-0.97%

An overview of all scenario inputs is provided in section 5.2. The following figure shows the redistribution as a function of an incrementing CO₂ allowance price:

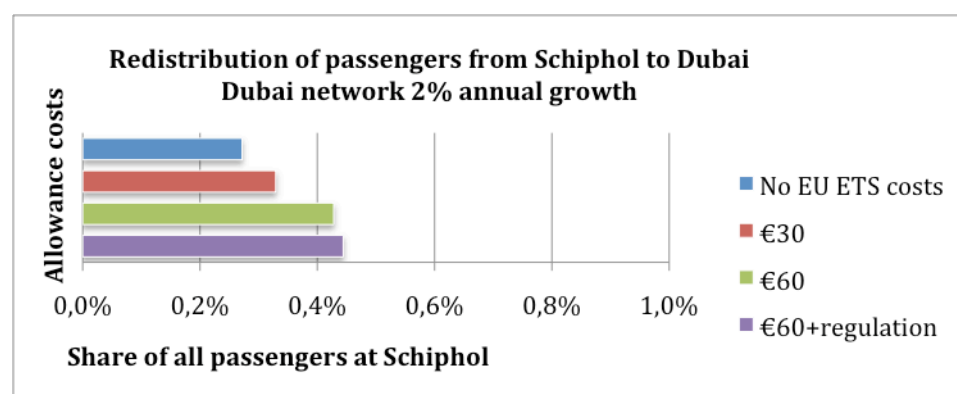


Figure 6.1: share of all Schiphol passengers switching under limited growth of Dubai network

In this figure it is shown what share of all passengers at Schiphol chooses to switch to Dubai under varying EU ETS costs. The upper blue bar shows this redistribution if airlines incur no additional costs as a result of the EU ETS, but Dubai extends its network by 2% annually. Similarly, the other bars show this redistribution if airlines need to purchase allowances at €30 or €60 per tCO₂. The lowest purple bar shows this redistribution under an allowance

price of €60 per tCO₂ combined with tighter regulation under the EU ETS, represented by a higher auctioning share and an annual lowering of the aviation emissions cap. Figure 6.2 below shows this impact under the same conditions, but with Dubai extending its network by 5% annually.

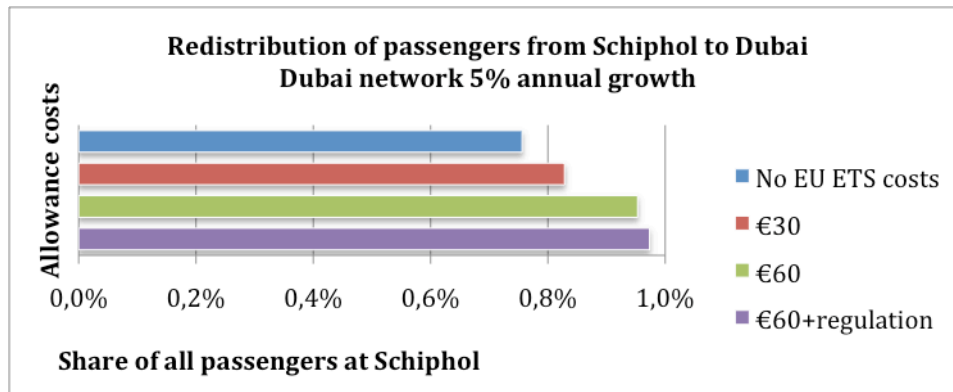


Figure 6.2: share of all Schiphol passengers switching under strong growth of Dubai network

6.2. Impact on specific market segments at Schiphol

The tables below show the redistribution in each scenario, differentiated per market segment.

Table 6.2: Overview of results per transfer market segment in all scenarios

Scenario	N.America - Asia	N.America - EU	Asia - EU	EU - EU	Total
0.1	-1.3%	-0.2%	-1.8%	-0.3%	-0.27%
0.2	-3.6%	-0.6%	-5.1%	-0.8%	-0.76%
1.1.1	-3.8%	-0.3%	-2.7%	0.1%	-0.33%
1.2.1	-6.7%	-0.7%	-6.2%	-0.3%	-0.83%
2.1.1	-6.7%	-0.4%	-3.8%	0.5%	-0.43%
2.1.2	-7.1%	-0.4%	-3.9%	0.5%	-0.44%
2.2.1	-10.4%	-0.8%	-7.5%	0.1%	-0.95%
2.2.2	-10.9%	-0.8%	-7.7%	0.2%	-0.97%
<i>(Share of segment)</i>	5%	5%	6%	30%	46%

Table 6.3: Overview of results per direct market segment in all scenarios

Scenario	Schiphol – N.America	Schiphol – Asia	Schiphol - EU
0.1	-0.1%	-4.3%	-0.1%
0.2	-0.2%	-5.6%	-0.3%
1.1.1	-0.1%	-6.6%	0.1%
1.2.1	-0.3%	-7.9%	-0.1%
2.1.1	-0.1%	-9.3%	0.2%
2.1.2	-0.1%	-9.7%	0.2%
2.2.1	-0.3%	-10.8%	0.1%
2.2.2	-0.3%	-11.2%	0.1%
<i>(Share of segment)</i>	5%	10%	33%

As can be seen in the tables above, on several market segments the amount of passengers switching to Dubai is below one percent. The total impact is not shown at the direct market segments, because a redistribution in these segments does not influence the total passenger redistribution, as indicated in section 4.3.

In the figure below only the three market segments where the share of passengers switching is above 1% are taken into account. These are transfer passengers travelling between North America and Asia and between Europe and Asia, and direct passengers between Schiphol and Asia:

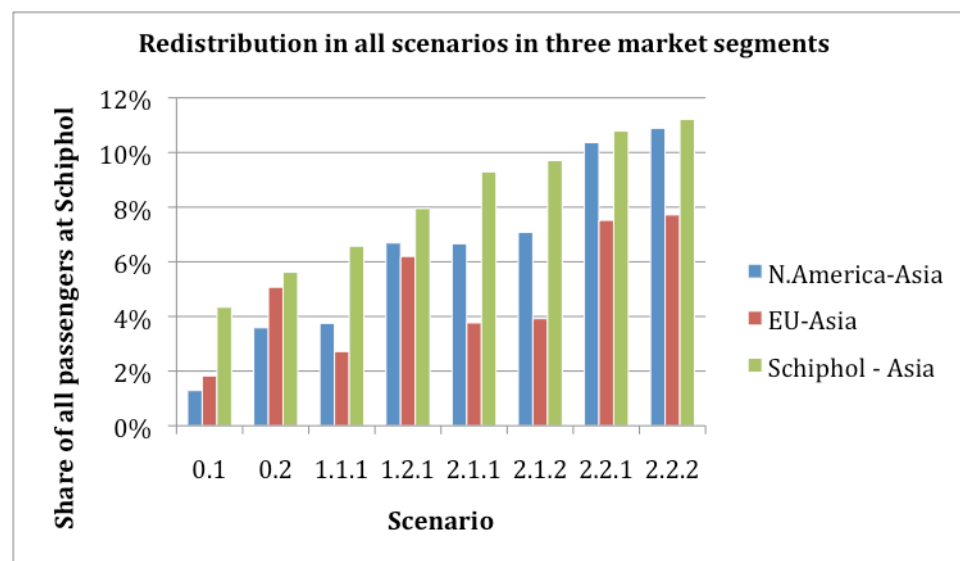


Figure 6.3: share of passengers switching to Dubai on significantly affected market segments in different scenarios

The figure above clearly shows that the share of direct passengers from Schiphol to Asia is most strongly affected by the rise of Dubai: even without the EU ETS more than 8% could switch to Dubai as shown in scenario 0.2. In contrast, transfer passengers between North America and Asia will hardly switch without the EU ETS (2% in 0.2), but in scenario 2.2.2 where EU ETS costs are the highest, over 7% will switch. The figures below show the redistribution of passengers in affected market segments as a function of an incrementing CO₂ allowance price: for each market segment it is shown what share of passengers will switch under different degrees of EU ETS costs, in a similar way as in the figures on the previous page:

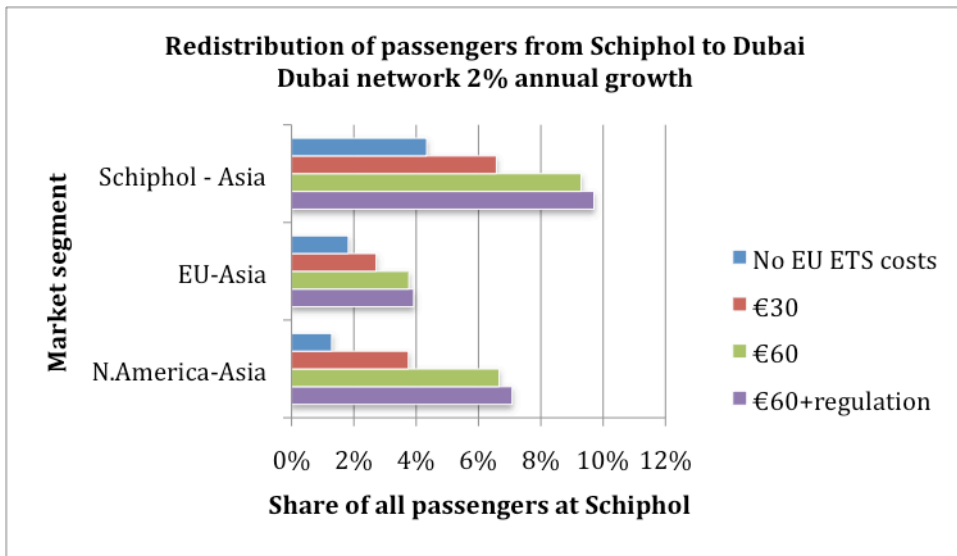


Figure 6.4: share of all passengers in certain market segments at Schiphol that switch to Dubai

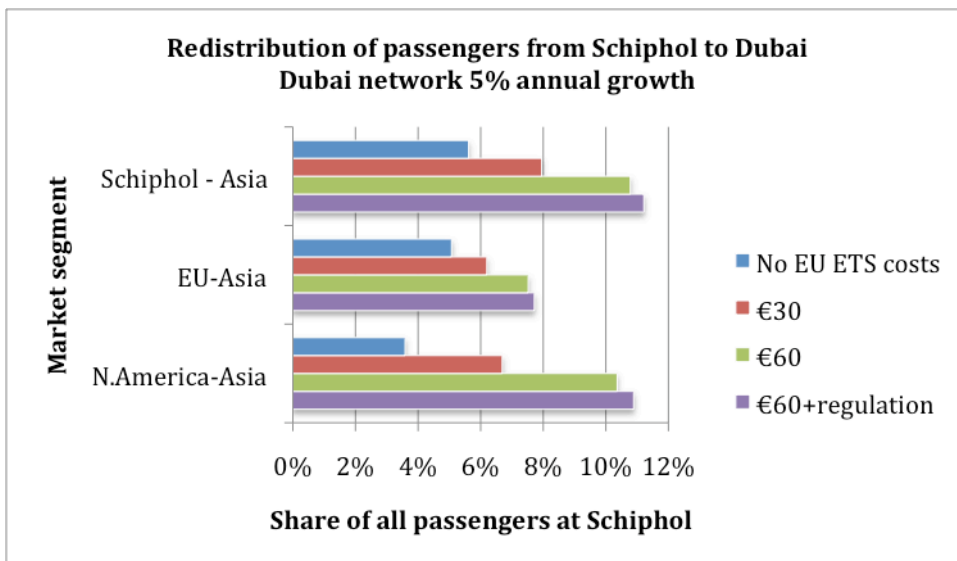


Figure 6.5: share of all passengers in certain market segments at Schiphol that switch to Dubai

These figures clearly show that the direct Schiphol-Asia market segment could be most strongly affected, but also that each of those market segments will even lose significant market share solely as the result of the growth of Dubai.

7. Analysis

As described in the introduction of this thesis, for this research a binary discrete choice model is used. As with any model, it is by definition a simplification of reality that includes assumptions on certain key factors. The resulting limits to the validity are presented in the next chapter. In this chapter the outcomes of the modelling part of this study are discussed, assuming this model and the assumptions made result in an accurate representation of reality. First a number of preliminary conclusions are drawn regarding the direct impact of the EU ETS, as indicated by the redistribution of passengers²⁴. Then, in section 7.2 the results of the performed sensitivity analysis are presented, and based on this analysis an overview of factors that strongly influence the outcomes of the model is given. Finally, in section 7.5 the effect on the network quality and economic attractiveness of Schiphol is assessed.

7.1. Interpretation of model outcomes

Overall redistribution effect limited

The overall redistribution effect of the EU ETS on Schiphol is limited: even in a ‘worst-case’ scenario the number of passengers switching to Dubai is likely to be less than one percent of all passengers that would travel through Schiphol if Dubai were not available.

Significant impact on Asian market

It should be noted that for three market segments the switch is more substantial: of all Schiphol passengers that fly between North America and Asia, Asia and the EU and directly from Schiphol to Asia, up to 11% percent could switch to Dubai. Accordingly, given the low margins of carriers, this could result in the abortion of certain direct destinations or the reduction of the frequency of services from Schiphol, resulting in a lower network quality as well. This has been elaborated in the next section.

7.2. Sensitivity analysis

The purpose of a sensitivity analysis is to determine the sensitivity of outcomes of the model to changes in parameters (the values of input variables). In case a small change in a parameter results in relatively large changes in the outcomes, the outcomes are considered sensitive to this parameter. This has two implications: first of all these parameters will need to be determined very accurately, since small adjustments have a significant effect on the

²⁴ It should be noted though this is not a comprehensive indicator of the impact of the EU ETS: direct passengers currently flying directly from Schiphol to their destination that choose to fly through Dubai instead will still depart from Schiphol and hence will not influence the number of passengers at Schiphol. However, this could still have an indirect effect, for example on the network quality of Schiphol.

outcome of the model. Secondly, this will aid the formulation of effective strategies by allowing one to focus on those parameters that are most significant to the outcomes.

In the specific case of this thesis, the main outcomes of the model are the overall passenger reduction at Schiphol and the passenger reduction per market segment. Since the scenario analysis has shown that passengers from Schiphol to Asian destinations are most likely to switch to Dubai as a result of the EU ETS, this market segment has been considered separately in the sensitivity analysis as well. A selection of input variables has been made: only policy variables or variables that are subject to change, for example as a result of technical innovation, have been taken into account. In this way, 'fixed values' that are crystal-clear like the density of kerosene or the distance between destinations are left out of the sensitivity analysis. In addition, coefficients for passenger preferences have been taken into account in this analysis, since these are subject to discussion and they could possibly vary in time or between different kinds of passengers. The sensitivity analysis has been performed with the conditions of scenario 2.1.1, since this is a scenario where EU ETS variables are not zero and most input variables have an average value. An overview of all the outcomes of this analysis can be found in appendix VII.

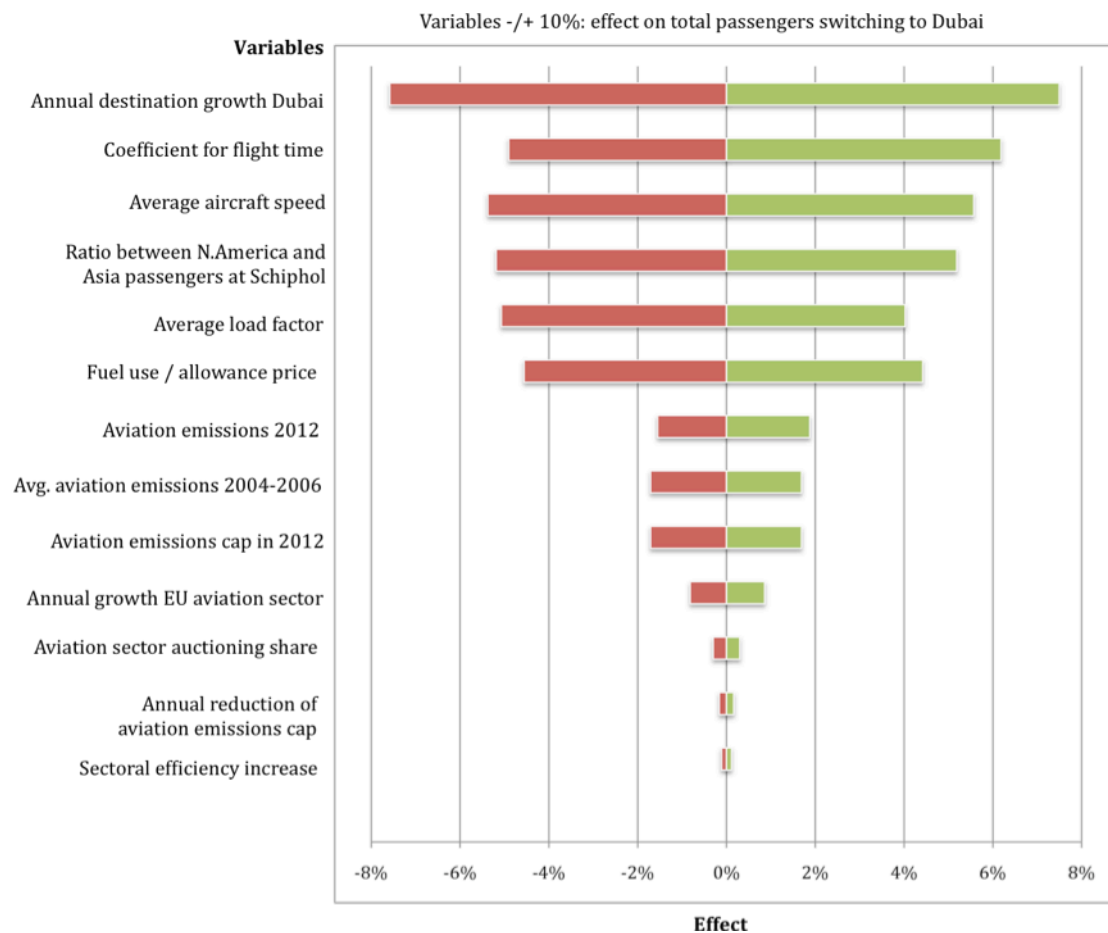


Figure 7.1: overview of sensitivity of all passengers at Schiphol

This chart shows how a 10% increase or reduction of one of the variables on the left of the chart affects the main output of the model: the total share of passengers switching from Schiphol to Dubai during phase III of the EU ETS. The variables on the upper side have the strongest effect on the output: for example, if the annual growth of destinations served from Dubai increases with 10%, the total number of passengers switching to Dubai will

increase with almost 8%. On the other hand, variables on the lower end of the chart have no significant effect: if the annual autonomous efficiency increase is improved by 10%, this will hardly increase the switch of passengers. The chart below shows the effect of variation of the same variables on a specific market segment: direct passengers from Schiphol to Asia.

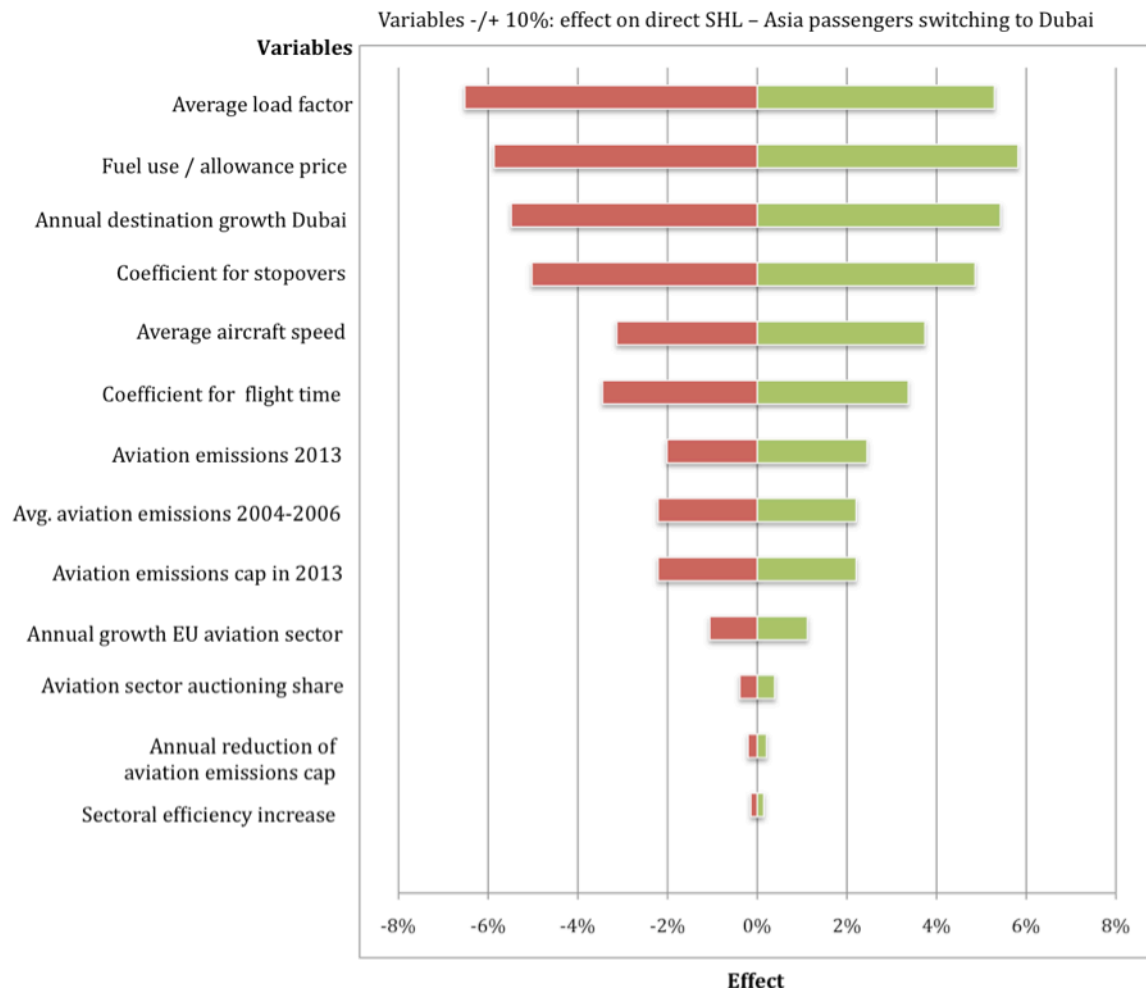


Figure 7.2: overview of sensitivity of passengers in Schiphol-Asia direct market segment

This chart shows the sensitivity of direct passengers between Schiphol and Dubai to several variables. Interestingly, compared with the previous chart other variables have the most significant effect on this market segment: for example, the average load factor is the most significant variables with over 6% effect. In the next section these results are discussed in more detail.

7.3. Main drivers of redistribution

The scenario analysis in chapter 5 and the sensitivity analysis in the previous section have provided great insight in the mechanisms that determine the amount of passengers that could switch from Schiphol to Dubai. Based on this insight several *main drivers* that largely determine the degree of redistribution have been identified:

Extra flight time

The main reason for the substantial switch in certain market segments has proven to be the geographical location of Dubai: the extra flying time compared with flying through Schiphol for flights to Asia is between 1 and 2 hours. In other market segments this extra flying time is between 9 and 10 hours. Given the Value of Time (VoT) of €13,54 per hour as described in section 3.4.2, it is clear why in the developed model there are almost no passengers switching in those market segments.

Expansion of Dubai network

As can be seen in the previous section, most of the redistribution of passengers would occur without emissions trading as well, solely as a result of the expansion of the network of Emirates: if the growth of this network is assumed 10% higher, the distribution will increase by almost 8%.

Share of Asian flights

The sensitivity analysis has pointed out that if the share of flights to North America increases, this will strongly reduce the shift of passengers to Dubai: if flights to North America increase by 10% at the expense of Asian flights, the switch to Dubai will decrease by about 5%.

Load factor

Obviously, the load factor is quite important as it determines the amount of passengers that the emission costs of a specific flight can be divided upon. As shown in the sensitivity analysis, on flights between Schiphol and Asia a 10% increase of the average load factor leads to a reduction in share of passengers switching by about 5%.

Efficiency of airplanes

In a similar way, more efficient airplanes will lead to a decrease in the emission costs per flight and thus on lower costs for passengers. On flights between Schiphol and Asia, an improvement of the fuel efficiency by 10% will reduce the switch to Dubai by more than 4%.

Fuel use / Allowance price

Changes in the fuel use and allowance price have the same effect, since in the model the fuel use only influences the emissions per passenger. A change of 10% in one of those factors can result in a passenger reduction of almost 6% on flights between Schiphol and Asia.

7.4. Factors with little effect

Based on the previous analyses, some factors were identified that have very little influence on the redistribution of passengers at Schiphol:

Share of transfer passengers on Asian destinations

As indicated by the scenario analysis, both transfer and direct passengers travelling between Schiphol and Asia could switch to Dubai as a result of the EU ETS. At first sight it seems

illogical that in fact even more direct passengers (up to 11%) than transfer passengers (up to 10%) could switch to Dubai, as for direct passengers this switch will lead to more additional travel time and an extra stopover. However, this can be explained by the fact that the network overlap of Schiphol and Dubai is limited outside of Asia: therefore, only 23% of transfer passengers find their origin and destination served from Dubai as well, while 82% of direct passengers find their destination served from Dubai.

Auctioning share for aviation sector

As explained earlier, this factor determines which share of allowances under the emissions cap will be auctioned. However, in the projected scenarios most emissions will be beyond this emissions cap due to the growth of the aviation sector, thus the effect of reducing the auctioning share will be limited: for example, reducing the auctioning share by 10% will only result in a 0.3% reduction in switching passengers. The figure below illustrates how the share of allowances under the cap makes up only a minor part of all allowances required by the aviation sector in 2012, as projected in the reference situation of the model:

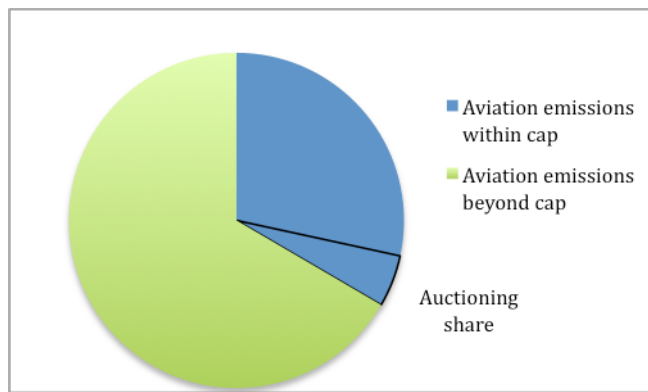


Figure 7.3: projected distribution of total allowances needed by aviation sector in 2012

Emissions cap for aviation sector

In a similar way, the emissions cap for the aviation sector is of limited significance: most emissions are expected to be beyond the cap, as illustrated in Figure 7.3 above.

Annual efficiency increase of aviation sector

Although this appears similar to increasing the fuel efficiency (which has a significant effect), this variable deals with the emissions of the aviation sector as a whole, and not with flights to and from Schiphol: as such it influences the total emissions, thereby determining to what extent aviation emissions exceed the emissions cap and must be paid for. As shown in figure 7.3 above, most emissions are expected to exceed the aviation emissions cap anyway, and thus the share of emissions that must be paid for will remain large. In addition, the allowance price is considered exogenous, and is thereby not influenced by emissions reductions of the aviation sector.

7.5. Analysis of network quality and economic attractiveness

In this section it is shown how the projected redistribution could affect the network quality of Schiphol by exerting influence on the number of direct destinations and frequencies

offered. To this end it is assumed that KLM (Schiphol's main carrier) is representative for all intercontinental carriers at Schiphol. Overall, the *break-even load factor* (BELF) on KLM flights is 78.0% for passengers (cargo is not taken into account in this study). This value can be calculated as follows (Van den Berg, 2009):

$$BELF = \text{unit cost per ASK} / \text{unit revenue per RPK} = 78.0\%$$

Where

Belf = Break-even load factor

ASK = Available Seat Kilometres

RPK = Revenue Seat Kilometres

Given the fact that KLM's average load factor over 2007 was 81.0%, it becomes clear that, on average, a reduction of more than 3% in the number of passengers on a certain destination will require a carrier to reduce the frequency of flights on that destination (or alternatively operate flights under the break-even load factor). However, this does not yet provide much insight in the impact on the network quality of Schiphol: some flights have such a high load factor or high frequency that a reduction will not have a significant impact on the network quality, while other, less popular destinations might be seriously affected if the amount of passengers decreases. To gain more insight in this impact, the total number of passengers and the resulting break-even frequency for several destinations under different scenarios has been calculated as follows:

$$\text{Average minimum number of passengers (avg. min no. of pass)} = \text{Average intercontinental airplane capacity} * BELF$$

And:

$$\text{Break-even frequency per week} = \text{Total passengers per week} / \text{avg. min no. of pass}$$

Since this calculation takes into account all passengers on a certain destination, it is irrelevant how many carriers compete on this route: because an equal *BELF* is assumed for all carriers, the resulting break-even frequency will be equal. In addition, it is assumed that carriers cannot switch to smaller airplanes because of their fleet configuration and the long distance of most routes concerned.

Since only eastern destinations seem to be severely affected under certain scenarios, three Asian destinations with a high, medium and low annual number of passengers have been examined to assess this impact. In Figure 7.4 below, the break even frequencies for flights from Schiphol to these destinations are shown, both under the reference situation and in the scenario with the maximum switch of passengers to Dubai. In addition, the minimal frequency that is required according to the analysis in sector 2.1.1 is shown (Van den Berg, 2009):

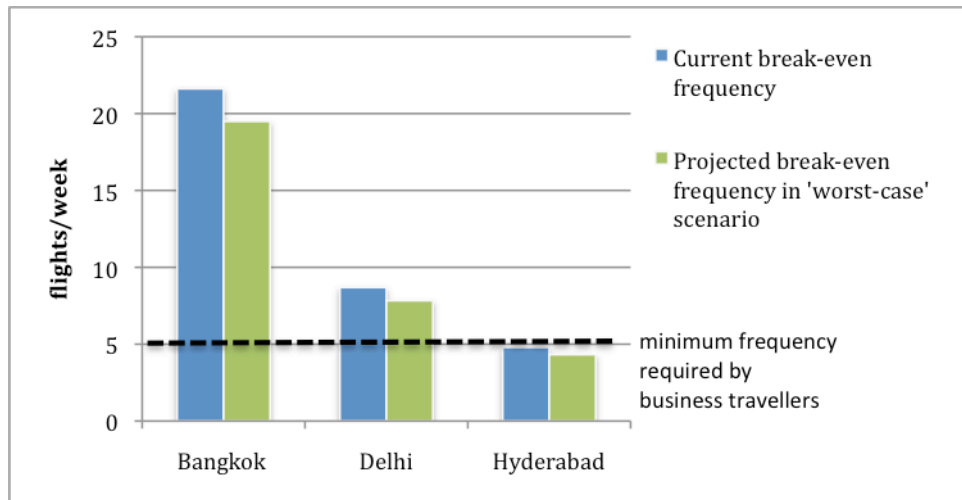


Figure 7.4: break-even frequency per week in current situation and 'worst-case' scenario

As shown in this figure, even in the scenario with the most impact the network quality of Schiphol remains adequate: on most destinations an adequate frequency can be maintained, as only on a few destinations with very little demand this frequency falls just below the minimum. Thus, it can be concluded the economic attractiveness is hardly affected.

7.6. Calculation of carbon leakage

Using the quantitative definition from section 2.3, the amount of carbon leakage has been calculated for all scenarios where emission costs are introduced, based on the projected redistribution of passengers. In addition, to put these numbers in perspective the annual amount of carbon leakage has been compared with the annual total emissions for the Netherlands. This is shown in the last column of the table below:

Table 7.1: annual carbon leakage in different scenarios

Scenario	Emissions without EU ETS (from switched passengers) ²⁵ [ton/yr]	Emissions with EU ETS (from switched passengers) [ton/yr]	Δ = annual carbon leakage [ton/year]	Carbon leakage (relative to passenger aviation to/from Schiphol)	Carbon leakage (relative to emissions under EU ETS in the Netherlands)
1.1.1	224,755	305,275	80,520	0.7%	0.1%
1.2.1	475,864	566,130	90,266	0.8%	0.1%
2.1.1	224,755	418,628	193,874	1.8%	0.2%
2.1.2	224,755	436,455	211,700	1.9%	0.3%
2.2.1	475,864	695,373	219,509	2.0%	0.3%
2.2.2	475,864	715,771	239,907	2.2%	0.3%

²⁵ To calculate the emissions without EU ETS, each scenario has been compared with the base scenario with the same conditions (0.1 or 0.2)

As shown in this table, the total carbon leakage is limited: in the scenario with the highest EU ETS costs (2.2.2), it is still below 2% compared with all emissions from aviation to and from Schiphol. However, if this percentage adds up in case all relevant airports are considered, this leakage could seriously harm European efforts to stabilize global CO₂ concentration.

7.7. Strategy development

Based on the previous section, it can be concluded that Schiphol Group does not need to take significant measures to reduce the impact of the EU ETS as the direct effects seem quite limited according to the developed model. In addition, the way the inclusion of aviation is implemented in the EU ETS puts the requirement to acquire allowances on airlines and not on airports. As a result, most measures that could mitigate the limited impact of the EU ETS should be taken by airlines. In this case this means Schiphol Group is largely dependent on KLM to take measures.

7.8. Conclusion of model analysis

Within the limitations of the used methodology, a number of conclusions can be drawn on the effect of the EU ETS on the position of Schiphol:

- Overall redistribution effect limited
- Significant impact on Asian market
- No impact on network quality of Schiphol
- No impact on the network quality of Schiphol

In the next chapter the limitations to the validity of these results are underlined.

8. Research limitations and validity

In this chapter the limits to the validity of the results presented in the previous chapter are underlined: although the research performed in this study has given considerable insight in the possible impact of the EU ETS on Schiphol, due to assumptions made and the approach chosen, the model developed for this research has certain limitations. It is important to emphasize these assumptions and limitations, in order to underscore inherent uncertainties, to prevent wrong interpretations of outcomes, and to indicate starting points for further research.

8.1. Overview of main assumptions

Static modelling approach

For this research a static modelling approach has been chosen. This has several important implications:

A static model shows the expected state of affairs at a given time: the model developed for this thesis calculates the equilibrium distribution of passengers under certain circumstances, and it is implicitly assumed that airlines and airports can directly adapt to those circumstances. In reality, reaching a new equilibrium takes time and will involve costs, for example because fixed costs associated with investments cannot be reduced quickly if demand falls (Boon et al., 2007). This holds true especially in the aviation sector, because of very long lead times between the order and delivery of an aircraft.

In a similar way, this static approach implies a unilateral relation between passenger demand and the flights operated by airlines, by assuming that it is solely the passenger demand that determines the redistribution of passengers. In reality passenger demand and the availability of flights influence each other.

Perfect inelasticity of demand assumed

As described in the introduction, the aim of this thesis is to explore the *redistribution effects* caused by the EU ETS. To model these effects it has been assumed the total demand for flights at Schiphol is perfect inelastic: passengers can choose to switch to Dubai, but since the choice whether or not to fly at all is not considered in the model, no conclusions can be drawn on the number of passengers that decide to fly under the EU ETS.

Binary model: only two airports

In this research a binary choice model has been used, which implies passengers only have a choice between two possible routes. In reality passengers can choose to fly through many airports, which can only be modelled with a more complex model.

Simplified network overlap

As pointed out in section 4.4, in this thesis it is assumed that there is a linear relationship between the degree of overlap in terms of destinations and in terms of passenger numbers. However, in reality this does not hold due to the characteristics of a hub-and-spoke network,

where an average intercontinental flight will carry passengers with many different origins and destinations. This is illustrated by figure 8.1 below, which is based on a flight from Frankfurt, an airport comparable to Schiphol.

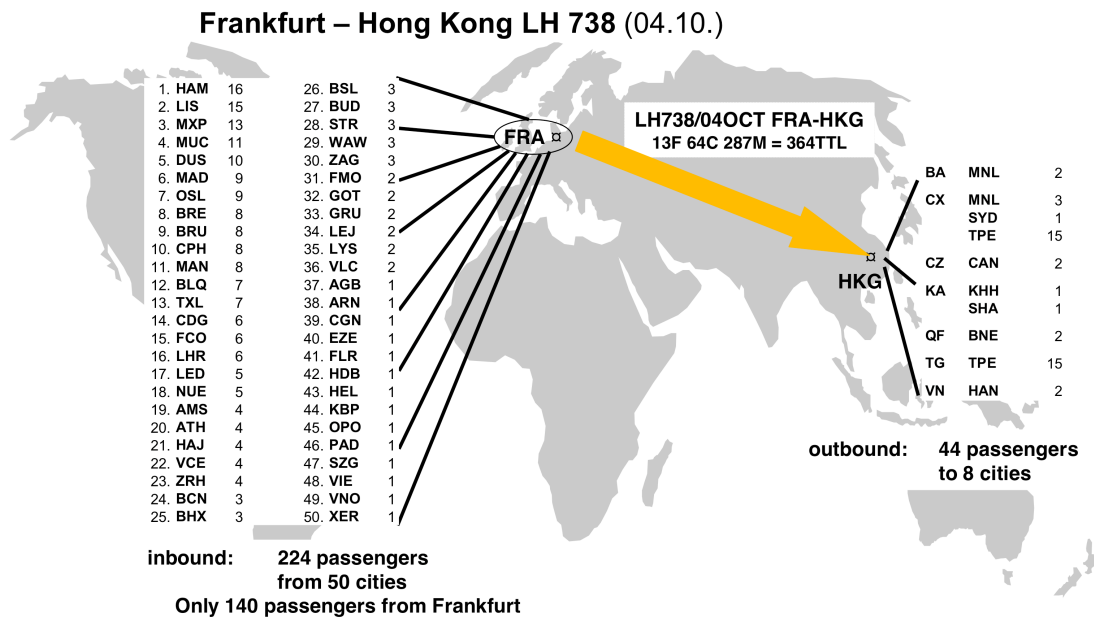


Figure 8.1: origins and destinations on an average intercontinental flight (taken from Hollmeier, 2006)

As shown in this figure, on a typical flight from Frankfurt to Hong Kong operated by Lufthansa there are passengers from fifty different origins, of which about 40% do not originate from Frankfurt airport and are therefore by definition transfer passengers. Thus, if a competitor like Emirates would operate flights from Frankfurt to Hong Kong, the 40% transfer passengers on the Lufthansa flight would not be able to switch to Emirates, unless Emirates would also operate flights to the origin airports of the transfer passengers. In addition, Emirates is not part of any alliance, making it even more difficult to cover the origins of all transfer passengers (Vespermann et al., 2008). Therefore, assuming the overlap in terms of destinations equals the overlap in terms of passengers that can switch will generally give an *overestimation* of the actual number of switching passengers.

Use of average distances for market segments

To predict the redistribution between Schiphol and Dubai caused by the inclusion of aviation in the EU ETS as accurately as possible, a model has to be developed that includes flight demand between all available city pairs from Schiphol. Furthermore schedule information for all possible airlines is needed, so that for each city pair the probability of passengers choosing either Schiphol or Dubai could be calculated. However, this requires a dataset with flight schedules and origin-destination-tables for all possible routes that is not publicly available. Therefore passenger flows have been researched on an aggregated level with average distances, which could result in a less accurate prediction.

Aggregate passenger preferences

The chosen modelling approach in this study does not allow for the use of differentiated passenger preferences, for example for business and leisure passengers. As indicated in section 3.4.3 and shown in studies from Hess (2007) and Loo (2008), business passengers appear less sensitive to cost differences, and therefore the effect of the EU ETS could be less in this segment. On the other hand, airlines often have higher margins on business passengers, and could therefore be more affected by a reduction in this segment (Van den Berg, 2009). Overall, it is unclear how this assumption could affect Schiphol.

Alternative specific constant (ASC) equal for Schiphol and Dubai

It has been assumed that passengers have no intrinsic preference for either Schiphol or Dubai. However, in reality there are a variety of reasons why passengers could have a preference for either one airport, for example based on good experiences in the past or an attractive tax-free zone.

Neoclassical assumptions

As described in the introduction, in this study it is assumed that travellers choose their route rationally and with complete information. However, the behaviour of real travellers is more complex and not so predictable.

Allowance price assumed exogenous

For this research it has been assumed that the price of an allowance is independent of developments in the aviation sector. In reality, a strong growth of the aviation sector is likely to influence the price of an allowance because it will lead to an increase in demand. In addition, there are interactions between the price of an allowance and the abatement efforts made by the aviation sector.

Outcomes based on coefficients from a different sample set

For this study the coefficients from a study by Hess (2007) have been used. These coefficients are based on a stated preferences study on the behaviour of passengers in the San Francisco area. It is well possible that preferences of passengers at Schiphol are different, for example because of different nationalities and different income levels. In addition, passenger preferences can change over time, for example if the income levels of passengers increase as a result of economic prosperity.

Single type of airplane assumed

It has been assumed that only one type of airplane is used and carriers cannot switch to smaller airplanes because of fleet configuration, long lead times and the long distance of most routes concerned (requiring large aircraft). Thus, this reduces the flexibility of carriers to increase the average load factor.

Linear relationship between distance and airfare

In this study it is assumed that there is a linear relationship between the distance of a route and the airfare. In reality the way airlines determine their ticket price on a certain route is much more complex and not transparent at all: KLM for example uses 22 different fare types

on an average flight. Generally, an airfare will depend on several characteristics of the route, amongst which (Van den Berg, 2009, Veldhuis and Lieshout, 2009):

- Distance
- Carrier type (hub-and spoke or point-to-point)
- Airline or alliance
- Average load factor
- Passenger travel purpose (business or leisure)
- Competition level on route

Full cost pass-through

If, contrary to the assumption in this thesis, airlines would not pass through all EU ETS costs to passengers, they would incur a loss and their operating margin would decrease (Boon et al., 2007). Given the low margins of airlines as demonstrated in chapter 7.5, it is likely that this will force airlines to adapt their operations to increase profitability. Although the developed model does not give insight in the effect on operating margins, it does provide an estimation of the total costs of the EU ETS for the aviation sector. Table 8.1 below shows these costs under different scenarios:

Table 8.1: total costs of EU ETS for aviation sector

Scenario	Total absolute costs for aviation sector (M€)
0.1	0
0.2	0
1.1.1	7,578
1.2.1	7,578
2.1.1	15,156
2.1.2	19,495
2.2.1	15,156
2.2.2	19,495

Although it is beyond the scope of this thesis to make any predictions on the profitability of airlines in each scenario, a ‘back-of-the-envelope’ calculation shows the impact would be significant: the operating results of European airlines vary strongly over the last years, but amounted to €3.7 billion in 2007 and €1.8 billion in 2006 (AEA, 2008). Assuming 75% of EU ETS costs are incurred by European airlines and the rest is incurred by non-EU airlines who fly on Europe, EU ETS costs seem very significant as they could amount up to €14 billion annually. Consequently, the assumption that airlines will pass through most of the EU ETS costs seems very probable since they do not have a sufficiently large profit margin to incur those costs themselves.

Price airlines pay for emissions equals allowance price

For this study, it is assumed that the price airlines will pay under auctioning for the right to emit one tonne of CO₂ will equal the market CO₂ price. In reality, this will depend on the way these rights are auctioned. For example, if auctioning takes place up front, the auctioning price can be expected to be equal to the future price of an allowance.

8.2. Influence and uncertainty of assumptions

Given the assumptions and limitations as described in the previous section, in this chapter a qualitative indication is given to what extent each assumption could influence the outcomes, and what the range of uncertainty for each assumption is. This assessment is based on the sensitivity analysis in sector 7.2, experience gained during the development of the model and analysis of the mechanisms as described in the previous chapters. Still it should be noted that this overview is by no means complete, and only serves as a starting point for further research:

Table 8.2: overview of importance of assumptions for results of study

<i>Assumption</i>	<i>Influence on outcome</i>	<i>Uncertainty/variance</i>
Static modelling approach	Strong	High
Perfect inelasticity of demand	Strong	High
Binary model: only two airports	Strong	High
Simplified network overlap	Strong	High
Single & homogenous passenger preferences	Strong	High
Allowance price considered exogenous	Limited	High
Use of average distances	Limited	Low
Single type of airplane	Limited	Low
Linear relationship airfare and distance	Limited	High
Linear relationship distance and flight time	Limited	Low
ASC equal for Schiphol and Dubai	Limited	High
Price airlines pay for emissions equals allowance price	Limited	Low

As can be seen in this table, there are several assumptions that exert a strong influence on the outcomes and of which the value could vary within a large range.

- Static modelling approach
- Perfect inelasticity of demand
- Binary model: only two airports
- Simplified network overlap
- Single and homogeneous representation of passenger preferences

9. Conclusions

The research undertaken for this Master thesis has provided considerable insight in the mechanisms that determine the effect of emissions trading on Schiphol airport. The main goal of this research was to provide insight for Schiphol Group in the significance and possible consequences of the inclusion of aviation in the European Emissions Trading Scheme (EU ETS) for the specific situation of Schiphol Airport. To this end, the main research question was formulated as follows:

What could be the impact of the inclusion of aviation in the European Emissions Trading Scheme on the position of Schiphol airport, and what strategy should Schiphol Group pursue to mitigate this impact?

To explore this impact, it has been assessed *what share of Schiphol passengers would switch to Dubai during phase III of the EU ETS²⁶ under different scenarios*. Dubai airport was chosen because it is one of the airports most likely to benefit from the inclusion of aviation in the EU ETS at the expense of Schiphol. The outcomes of this research clearly indicate that the impact of the EU ETS on the position of Schiphol airport during phase III is limited under all evaluated scenarios, and there is no need for Schiphol Group to pursue a strategy to mitigate this impact. With regard to the sub research questions as formulated in chapter 1, this research has yielded the following outcomes:

1. The total number of passengers that will switch to Dubai during phase III of the EU ETS can be expected to be between 0.3% and 1% of all passengers at Schiphol, even in a 'worst-case' scenario from Schiphol's perspective. However, most of this redistribution would take place without the EU ETS as well, simply as a result of the growth of the network of Dubai airport and carriers like Emirates airlines. Hence, inclusion of aviation in the EU ETS will only induce a very limited redistribution of passengers from Schiphol to Dubai.
2. For three specific market segments there could be a larger redistribution of passengers, depending on the scenario:
 - 1-11% of all transfer passengers flying between North America and Asia with a stopover at Schiphol could switch to Dubai.
 - 2-8% of all transfer passengers flying between Europe and Asia with a stopover at Schiphol could switch to Dubai.
 - 4-11% of all direct passengers between Schiphol and Asia could decide to fly with a stopover at Dubai.

A major share of this redistribution can be attributed to cost differences caused by the EU ETS. For the other market segments, the redistribution will remain below one percent.

These results indicate that it is mainly the Asian market that is affected by the EU ETS. Since this is not Schiphol's primary market, both in terms of profitability and in terms of passenger numbers, this explains the limited impact on Schiphol as a whole. In addition, if direct passengers choose to fly through Dubai, they will still use Schiphol as their final arrival or departure airport. Yet, KLM and other carriers at Schiphol could be affected by this redistribution, as Dubai-based carriers could

²⁶ Phase III of the EU ETS commences in 2013 and ends in 2020

employ their own feeder flights to bring passengers to their hub. Because of the strong relation between KLM and Schiphol, the position of the latter could be indirectly influenced in this way.

3. The network quality of Schiphol is hardly affected: given the current flight demand, on nearly all destinations it will be possible to maintain a frequency of at least 5 flights per week in a cost-effective way. This is considered the minimal acceptable frequency for business travellers from companies that frequently use Schiphol. Accordingly, the economic attractiveness of the Schiphol region is unlikely to be seriously affected by the EU ETS. On an individual level there might be companies that are mainly dependent on the Asian market who find a decrease in direct flights to that region problematic. Still, on a whole this will not affect the Schiphol region significantly.

However, in conjunction with other factors like the liberalization of the aviation sector and the aftermath of the current economic crisis, it is possible that the EU ETS provides the 'tipping point' that results in a strong reduction of the network quality of Schiphol. Also, it should be noted that on an individual carrier level, even this limited redistribution could cause the termination of service on certain destinations, because of the small operating margins of airlines as indicated in section 7.5.

4. Carbon leakage as a result of the EU ETS and switching passengers to Dubai could amount up to 250 kton CO₂ annually, around 2 percent of emissions of flights to and from Schiphol, or 0,3% of all emissions in the Netherlands under EU ETS. If this effect occurs at other European airports as well, it could significantly undermine European efforts to mitigate global CO₂ emissions.
5. Several main drivers have been identified that largely determine the degree of redistribution:
 - The expansion of Dubai's network
 - The share of Asian flights operated from Schiphol
 - The average load factor
 - The efficiency of airplanes
 - The allowance priceIn contrast, the following factors have almost no effect on the redistribution of passengers:
 - The share of transfer passengers at Schiphol
 - The auctioning share for the aviation sector
 - The emissions cap for the aviation sector
 - Annual efficiency increase of aviation sector

6. Since the impact of the EU ETS is limited, there is no urgency for Schiphol Group to pursue a strategy to mitigate this impact. In addition, most measures that could mitigate this impact - in case it turns out to be more severe – need to be taken by airlines. Still, it is recommended that Schiphol pursues a 'no-regret' policy as described in the next chapter.

With regards to the conclusions above, the reader must be aware of the limitations to the validity of these outcomes: several major assumptions were made during this research, and certain factors were simplified or left out of the model. For example, the simplified network overlap between Schiphol and Dubai probably gives an overestimation of the

redistribution effects. The following assumptions are expected to strongly influence the outcomes:

- Static modelling approach
- Focus on redistribution of passengers
- Binary model: only two airports
- Simplified network overlap
- Single and homogeneous representation of passenger preferences

10. Recommendations

The outcomes of this research indicate that there is no need for Schiphol Group to implement any drastic measures to deal with the forthcoming inclusion of aviation in the EU ETS: in any scenario the overall redistribution of passengers is limited, and most of this redistribution can be attributed to the autonomous growth of Dubai and not to the EU ETS itself. In addition, there are limited options for Schiphol Group to mitigate this impact, as most effective measures need to be implemented by carriers, most notably KLM. However, due to the large number of assumptions used in the research there are certain uncertainties with regard to these outcomes. Therefore it is recommended that Schiphol Group implements a 'no-regret' policy to deal with these uncertainties without committing to unnecessary, expensive steps. This policy consists of the following three 'pillars':

- 1) Measuring the developments in this field
- 2) Perform additional research to reduce uncertainties
- 3) Implementing low-cost measures to mitigate the impact

Each pillar is elaborated in the following sections:

10.1. Measuring developments

As shown in chapter 8, the presented outcomes are based on a large number of assumptions. Because of this, the actual impact could differ. Therefore it is recommended that Schiphol Group actively monitors the following factors to be able to anticipate a larger impact:

- *Network overlap between Schiphol and Dubai*
As indicated in chapter 7.2, the network overlap between Schiphol and Dubai largely determines the redistribution of passengers. To this end it is particularly important to monitor the policies of carriers at Dubai with regard to new destinations in Europe and Asia, as an increasing coverage in these regions is expected to have the largest impact on Schiphol's position.
- *The share of Asian flights*
Similarly, the share of Asian flights at Schiphol has a strong influence on the redistribution. Schiphol Group could monitor this by closely following expansion plans of carriers at Schiphol, most importantly KLM.
- *European climate policy*
Obviously, the development of the European policy on climate change is relevant for Schiphol Group, as it largely determines the impact of the EU ETS. This research has shown that the allowance price strongly influences the degree of redistribution, and therefore it should be closely monitored. In addition, it should be noted this research indicates that the auctioning share and the emissions cap for the aviation sector are of minor importance, and as such are no good indicators. This is further explained in section 7.4.

10.2. Perform additional research

As indicated earlier, there is uncertainty with regard to the outcomes of this research: certain factors were left out of the model and others were included in a simplified form. It is recommended that Schiphol Group mitigates this uncertainty by performing additional research on the following topics:

- *Develop multi-airport model*
First and foremost, it is strongly recommended that the method that has been developed for this Master thesis is adopted in order to be able to include multiple airports, and be applied to other major hubs in Europe as well. This will require a method to deal with the overlap between multiple airports.
- *Measure network overlap in terms of passenger numbers*
A more accurate method should be developed to estimate the actual overlap between Dubai and Schiphol in terms of passenger numbers, as described in section 4.4. The author recommends the possible use of a dataset with flight demand for each possible city-pair from Schiphol. Such sets, for example the OAG database, are commercially available. Institutes like SEO also have extensive experience in this field, and their methods could provide a useful starting point.
- *Determine differentiated passenger preferences at Schiphol*
In order to accurately predict the behaviour of passengers, it is necessary to obtain the preferences of actual passengers at Schiphol, and to differentiate between business and leisure passengers. In addition, these preferences would need to be updated on a regular basis to reflect changing passenger behaviour. This could be achieved by performing a stated preferences survey among all types of passengers at Schiphol on a regular basis, for example once per year.

10.3. Implementing low-cost measures

Several low-cost measures have been identified during the research, for example based on insight gained during the modelling process, by interviews and from literature. These measures could be implemented in a precautionary way, or in case monitoring or research programmes as described above indicate a larger impact of the EU ETS than predicted in this research. These measures can be considered low-cost 'no-regret' measures because they can be implemented without significant costs and will most likely be beneficial to Schiphol Group regardless of the actual impact of the EU ETS.

- *Emphasizing Schiphol's green image*
As indicated in the introduction, Schiphol Group has already expressed the intention *grow in a sustainable matter* (Schiphol Group, 2009). When travellers become more aware of environmental issues and their 'carbon footprint', it could be worthwhile for Schiphol to emphasize the sustainability of flights through Schiphol versus flights through non-EU hubs like Dubai.
- *Start joint lobbying effort with European main airports*
As shown in appendix VIII, it appears most European major hubs could face similar redistribution effects as Schiphol. It could therefore be beneficial to start a joint

lobbying effort with airports like Frankfurt, Paris and London. This lobby should focus to obtain more possibilities to compensate carriers on routes where the effects of the EU ETS are the largest. More specifically, two adjustments are proposed:

➤ *Liberalize slot allocation*

Currently, an independent slot coordinator is responsible for the allocation of slots at airports, to ensure landing and take-off slots '*are used efficiently and distributed in an equitable, non-discriminatory and transparent way*' (European Council, 1993). As a result, airports cannot choose to give preference to market segments where the impact of the EU ETS is large.

➤ *Allow for differentiated airport taxes*

In a similar way, according to European law airports are not allowed to differentiate airport taxes between destinations (European Commission, 2006a). If airports were allowed to differentiate airport taxes to give preference to market segments where the impact of the EU ETS is large, in this way the impact of the EU ETS could be reduced.

11. Reflection

In chapter 8 of this research the implications of assumptions and simplifications *within* the scope of this thesis have been addressed. In this section it is analyzed how factors *outside* the scope of this thesis could influence the impact of the inclusion of aviation in the EU ETS. In addition, attention is paid to the trade-offs that intrinsically play a role when discussing airport growth: the complex interplay between political, economic and strategic reasons makes decision-making in the field of airport planning more complicated than one could perceive based on the previous chapters. Therefore in this section a wider, qualitative overview of other important factors and trade-offs is given, based on relevant literature and the interviews held at KLM, Schiphol Group and the research institute SEO. This overview aims to provide an overview of relevant research areas for Schiphol Group with regard to the impact of the EU ETS, and thereby provides a starting point for further research.

Relation between Schiphol and KLM

An important aspect that falls outside the scope of this thesis is the relation between Schiphol and KLM: since KLM is the main carrier at Schiphol that operates flights on roughly half of all intercontinental destinations (Van Unnik, 2009), it is safe to conclude that any significant effect of the inclusion of aviation in the EU ETS on KLM will also affect Schiphol indirectly. It is well possible that the impact on KLM will be significantly larger: in section 4.3 it has been described that the redistribution of direct passengers will not affect Schiphol as these passengers will still have their final origin or destination there. However, KLM and other carriers at Schiphol could be affected by this redistribution: because Gulf carriers like Emirates are not part of an alliance they will need to employ their own feeder flights to bring passengers to their hub (Vespermann et al., 2008), at the cost of Schiphol-based carriers. In addition, this could influence the network quality of Schiphol because in this way the number of passengers flying from Schiphol directly to their destination will reduce, resulting in a lower break-even frequency in market segments where a significant redistribution of direct passengers takes place.

Capacity constraints

Regarding the capacity of an airport, a distinction should be made between the *physical capacity* and the *environmental capacity*. The physical capacity is mainly constrained by the capacity of the runways, and is determined to be 640.000 annual air transport movements (Ministerie V & W, 2007). It should be noted that this figure is related to the 'wave-structure' used by major carriers like KLM, where large numbers of flights come in within a short time span, in order to minimize waiting times and maximize connectivity for transfer passengers. However, this high peak load results in more delays and less efficient use of resources. Thus, a trade-off exists between high connectivity on the one side and high reliability and efficient use of resources on the other hand (Van Unnik, 2009).

The environmental capacity is constrained by noise limits, and is on the short term set to 480.000 air transport movements (Ministerie V & W, 2007). Given the fact that flight movements on Schiphol neared 450.000 in 2007, there is limited space for growth under the current limits.

These capacity constraints could limit the impact of the EU ETS: for example, if due to capacity constraints passenger demand at Schiphol exceeds the available capacity, there will be no net effect if some of those passengers chooses to fly through Dubai, as long as the remaining demand exceeds Schiphol's capacity.

Technological developments

The development of medium-sized long-range aircraft by Boeing like the 777 supports the operation of direct point-to-point flights, at the expense of indirect flights. This strategy, also referred to as *hub bypassing*, stands opposite to the Airbus strategy of developing very large aircraft that fit within a hub-and-spoke strategy and profit from economies of scale. The figure below gives a schematic representation of both strategies:

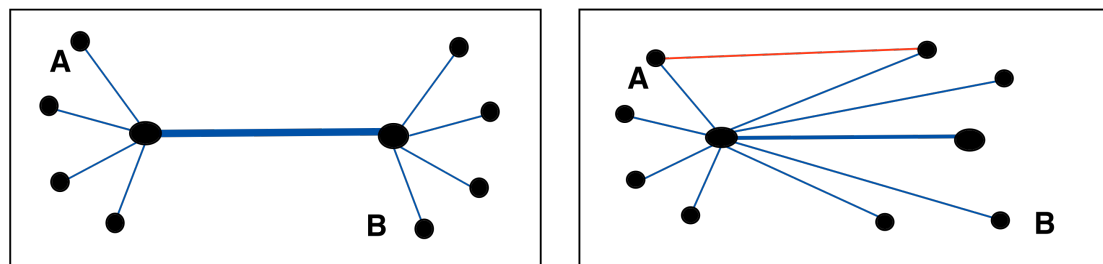


Figure 11.1: overview of hub-and-spoke strategy (left) and point-to-point strategy (hub bypassing) (taken from Schiphol Group, 2007d)

If point-to-point becomes the prevailing strategy, this could threaten the position of Schiphol, since it is largely dependent on transfer passengers as described in the introduction of this thesis. However, which one becomes the dominant strategy will also depend on other factors like the changing preferences of passengers and the growth of aviation demand (Van den Berg, 2009).

Liberalization and competition

It is expected that international 'open-skies'-agreements will soon allow more airlines to operate on intercontinental routes, thereby leading to an increase in competition possible causing lower airfares. In addition, this could fuel the rise of intercontinental Low Cost Carriers, thereby further decreasing the importance of hub-and-spoke networks as described earlier. In addition, on the long term this could reduce the binding of airlines to countries, which could hypothetically lead to the relocation of a carrier like KLM to another hub. Obviously this would strongly influence the position of Schiphol (Ministerie V & W, 2007).

Rise of Low Cost Carriers

As described above, the liberalization within the European Union has led to the entrance of many new airlines, of which a large share exists of Low Cost Carriers (LCC's). These LCC's have influenced the aviation sector in multiple ways. In the case of Schiphol, they allowed a higher utilization of the airport capacity by using off-peak hours. This allowed Schiphol to realize lower tariffs for airlines. On the other hand, they competed with KLM, threatening the feeder-flights of KLM that are necessary to maintain a hub-and-spoke network. However, by flying to new destinations as well they also increased the network quality of Schiphol (Ministerie V & W, 2007). It can therefore be concluded that the effect of LCC is mixed, and additional research is necessary to determine how they effectively impact the network quality of Schiphol.

Development of global aviation

The future worldwide growth of aviation in the coming years will be strongly influenced by rising economies. Most of this growth will take place in the *BRIC countries*, an acronym for Brazil, Russia, India and China. These countries are quickly becoming the emerging economies of the 'next' world, and are expected to become the world's four most dominant economies by 2050, larger than that of the US and Western Europe combined (Wilson and Purushothaman, 2003). It is generally expected that this will result in a doubling of the worldwide size of aviation in the next twenty years (Schafer and Victor, 2000). On the one hand, this will lead to new connections from existing markets, mainly Europe and the US. On the other hand, residents of BRIC countries will travel more themselves. Due to the large populations, the impact will be especially large from India and China (Schiphol Group, 2007a).

It is well possible that certain non-EU hubs like Dubai are geographically better positioned to handle traffic to those countries (O'Connell, 2006), and so the increase of aviation demand from those countries could result in certain non-EU hubs gaining a competitive advantage at the expense of European hubs like Schiphol. Given the fact that this research has shown that especially the Asian market segment at Schiphol is likely to be affected by the EU ETS, this effect could even be stronger (three BRIC countries are Asian).

Alliances and mergers

Airlines worldwide have used the formation of alliances to extend their network coverage and reduce costs. This has particularly benefitted Schiphol since KLM was the first airline to form an alliance with Northwest, and is one of the reasons Schiphol has become such an important hub. However, new developments like the recent merger with Air France could also influence Schiphol in a negative way: Paris Charles De Gaulle (CDG) could become the primary hub of the SkyTeam alliance, thus reducing the importance of Schiphol. An effect that can already be observed is the fact that the new 'supersize' Airbus A380 airplanes will only be flying on Paris CDG, and not on Schiphol (Ministerie V & W, 2007). However, the actual impact will also largely depend on the global development of aviation as described in the previous section.

Development of other modalities

The impact of the development of other modalities, mainly high-speed rail connections, is also mixed: on the one hand this can increase the catchment area of Schiphol, thus increasing the number of direct passengers and reducing the dependency on transfer passengers. On the other hand, it could jeopardize short-range feeder flights that are necessary to maintain the hub-and-spoke network (Ministerie V & W, 2007).

Network quality versus competition between carriers

In the past, the prevalence of the network development of KLM in policies regarding Schiphol has strongly contributed to the high network quality. As indicated in chapter 10, a possible way to maintain this network quality is to develop a selective slot allocation strategy. However, a trade-off exists between network quality prevalence and the development of competition between airlines: if more priority is given to the development of competition between carriers, this could benefit the local market by resulting in lower prices at the expense of network quality. Therefore these goals should be carefully considered when formulating a future strategy, since on the long term the combination of a

high network quality and the facilitation of more competition is unfeasible, given the capacity constraints as formulated earlier (Kuipers et al., 2007).

A national perspective versus a European perspective

This study has provided insight in the impact of the EU ETS on a regional and national level. Consequently, the conclusions provided in the next chapter support the formulation of new policies regarding Schiphol from this perspective. However, an optimization strategy from the point of view of Europe would yield different result: for example, from a European perspective an optimal setup and hierarchy of hub-airports would yield a different role for Schiphol than provided in this research (Kuipers et al., 2007). Therefore, additional research should be performed to give insight in the effects of the EU ETS and possible strategies from a European point of view.

References

- AEA (2008) *Airline Economics*. Retrieved March 30, 2009, from <http://www.aea.be/research/economics/index.html>.
- Air France KLM (2008) *Inclusion of air transport in emissions trading scheme*. Retrieved April 15, 2009, from <http://Corporate.Airfrance.Com/En/Strategy/Commitments/Environment/Inclusion-of-Air-Transport-in-Emissions-Trading-Scheme/Index.Html> (Ed.).
- Alamdari, F. E. & Black, I. G. (1992) *Passengers Choice of Airline under Competition - the Use of the Logit Model*. *Transport Reviews*, 12, 153-170.
- Beimann, B. (2007) *The European Emissions trading scheme and the impacts on the European transfer traffic volume*. European Center for Aviation Development.
- Boon, B., Davidson, M., Faber, J. & Velzen, A. v. (2007) *Allocation of allowances for aviation in the EU ETS - The impact on the profitability of the aviation sector under high levels of auctioning*. Delft, CE Delft.
- Bowen, J. (2004) *World-Shapers: The Geographical Implications of Several Influential Jet Aircraft*. *Conference of the American Association of Geographers*.
- Bows, A. & Anderson, K. (2008) *A bottom-up analysis of including aviation within the EU's Emissions Trading Scheme*. Tyndall Centre for Climate Change Research.
- Bows, A., Upham, P. & Anderson, K. (2005) *Growth Scenarios for EU & UK Aviation: contradictions with climate policy*. Tyndall Centre for Climate Change (North).
- Burghouwt, G., Lieshout, R., Zuidberg, J., Wit, J. d. & Veldhuis, J. (2008) *Concurrentie analyse Amsterdam Schiphol 2007 - Concurrentiepositie in het wereldwijde luchtvaartnetwerk*. Amsterdam, Stichting Economisch Onderzoek.
- CE Delft & MVA Consultancy (2007) *Implications of EU Emission Trading Scheme for Competition between EU and Non-EU airlines*. Delft.
- Chorus, C. (2009) *Personal interview*. TU Delft, Delft.
- Davidson, M., Faber, J. & Bruyn, S. d. (2008) *Competitiveness issues for Dutch aviation from EU ETS*. Delft, CE Delft.
- De D. Ortuzar, J. & Willumsen, J. G. (1994) *Modelling transport*, John Wiley & Sons.
- Dennis, N. (1999) *Competition between airports for long-haul traffic from Europe*.
- Ernst & Young (2007) *Analysis of the EC proposal to include aviation activities in the emissions trading scheme*.
- Euractiv (2008) *Deal clinched on capping aircraft emissions*. Retrieved April 20, 2009, from <http://www.euractiv.com/en/transport/deal-clinched-capping-aircraft-emissions/article-173722>
- European Commission (2006a) *European Commission delivers a reasoned opinion to Malta* Retrieved April 15, 2009, from <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1776&language=en>.
- European Commission (2006b) *Impact Assessment of the inclusion of aviation activities in the scheme for greenhouse gas emission allowance trading within the Community*.
- European Commission (2008) *Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community*.
- European Council (1993) *Council Regulation (EEC) No 95/93 of 18 January 1993 on common rules for the allocation of slots*.

- Eurostat (2009) *EU 'Single Sky' agreement in sight*. Retrieved May 10, 2009, from <http://epp.eurostat.ec.europa.eu/>
- Frassek, B. (2009) *Astronomy Answers - Great Circles*. Retrieved April 10, 2009, from <http://www.astro.uu.nl/~strous/AA/en/reken/grootcirkel.html>.
- Gagelmann, F., Hansjurgens, B. (2002) *Climate protection through tradable permits: the EU proposal for a CO2 emissions trading system in Europe*. *European Environment*, 12, 185-202.
- Gordijn, H., Harbers, A., Nabielek, K. & van der Veecken, C. (2007) *De toekomst van Schiphol*. Green Air Online (2009) *Fuel efficiency aspirational goals form the main achievement of the GIACC process to address climate change*.
- Harvey, G. (1987) *Airport choice in a multiple airport region*. *Transportation Research Part A: General*, 21, 439-449.
- Hess, S. (2007) *Posterior analysis of random taste coefficients in air travel behaviour modelling*. *Journal of Air Transport Management*, 13, 203-212.
- Hess, S. (2008) *Treatment of reference alternatives in stated choice surveys for air travel choice behaviour*. *Journal of Air Transport Management*, 14, 275-279.
- Hollmeier, S. (2006) *Long haul - Growth opportunities and challenges*. FEAMA. Gothenburg.
- Horth, D. & Alwyn, T. (2005) *UBS Investment Research: The next low-cost threat*. *Global Equity Research*.
- Hutchinson (2009) *Market Segment*. Retrieved April 25, 2009, from <http://encyclopedia.farlex.com/Market+segment>
- IATA (2008) *IATA economic briefing - the impact of recession on air traffic volumes*. The International Air Transport Association.
- IATA (2009a) *Passenger Decline Stabilizes - Some Improvement in Freight*. <https://www.iata.org/pressroom/pr/2009-06-25-01.htm>. Geneva, The International Air Transport Association.
- IATA (2009b) *State of the Air Transport Industry*. Kuala Lumpur, Malaysia, The International Air Transport Association.
- INCHEM (1998) *Kerosene*. Retrieved April 23, 2009, from <http://www.inchem.org/documents/icsc/icsc/eics0663.htm>.
- Jardine, C. N. (2009) *Calculating The Carbon Dioxide Emissions Of Flights*. Environmental Change Institute.
- Kanafani, A. & Ghobrial, A. A. (1985) *Airline hubbing--Some implications for airport economics*. *Transportation Research Part A: General*, 19, 15-27.
- KLM (2009a) *Duurzamer vliegen*. Retrieved May 10, 2009, from <http://www.klm.com>
- KLM (2009b) *Stoelindeling Boeing 777-200*. Retrieved May 10, 2009, from http://www.klm.com/travel/nl_nl/travel_informations/on_board/seating_plans/777-200ER.htm.
- Kolkman, J. & Korteweg, J. A. (2009) *Internationale benchmark capaciteit luchthavens*. Kennisinstituut voor Mobiliteitsbeleid.
- Kuipers, B., Manshanden, W. J. J., Koops, O., Verweij, C. A., Veldhuis, J., Rosenberg, F. & Schouten, E. (2007) *Maatschappelijk-economische analyse mainport Schiphol*. Delft / Amsterdam / Huizen, TNO / SEO / Ministerie van Verkeer & Waterstaat.
- Loo, B. P. Y. (2008) *Passengers' airport choice within multi-airport regions (MARs): some insights from a stated preference survey at Hong Kong International Airport*. *Journal of Transport Geography*, 16, 117-125.
- Ministerie V & W (2007) *Lange termijn verkenning Schiphol - Probleemanalyse*.
- MVA Consultancy (2006) *Consequences for the Dutch Aviation Sector of Inclusion in the European Emission Trading Scheme*.

- Nieuwsblad Transport (2006) *Schiphol vreest Dubai niet*. Retrieved March 25, 2009, from http://www.nieuwsbladtransport.nl/site.php/1860/nieuwsitem/Schiphol_vreest_Dubai_niet_.html
- O'Connell, J. F. (2006) *The changing dynamics of the Arab Gulf based airlines and an investigation into the strategies that are making Emirates into a global challenger*. *World Review of Intermodal Transportation Research*, 1, 94-114.
- Omega (2009) *Climate Change - The Rising Effect of Aviation on Climate - Global temperature change implications of projections of aviation growth in the context of GHG emission mitigation scenarios*.
- Schafer, A. & Victor, D. G. (2000) *The future mobility of the world population*. *Transportation Research Part A: Policy and Practice*, 34, 171-205.
- Scheelhaase, J. D. & Grimme, W. G. (2007) *Emissions trading for international aviation--an estimation of the economic impact on selected European airlines*. *Journal of Air Transport Management*, 13, 253-263.
- Schiphol Group (2007a) *Een wereldwijd netwerk voor een concurrerende Randstad - Lange termijn visie op de ontwikkeling van de mainport Schiphol*.
- Schiphol Group (2007b) *Facts & Figures 2007*. Retrieved April 5, 2009, from <http://www.schiphol.nl>
- Schiphol Group (2007c) *Statistical annual review 2007*. Retrieved April 5, 2009, from <http://www.schiphol.nl>
- Schiphol Group (2007d) *Werken aan de toekomst van Schiphol en de regio*. Retrieved April 5, 2009, from <http://www.schiphol.nl>
- Schiphol Group (2008) *Factsheet Schiphol*. Retrieved April 5, 2009, from <http://www.schiphol.nl>
- Schiphol Group (2009) *Sustainable growth*. Retrieved April 5, 2009, from <http://www.schiphol.nlhttp://www.schipholgroup.nl/CorporateResponsibility1/SustainableGrowth.htm>.
- Sijm, J. P. M., Kuik, O. J., Patel, M., Oikonomou, V., Worrell, E., Lako, P., Annevelink, E., Nabuurs, G. J. & Elbersen, H. W. (2004) *Spillovers of Climate Policy - An assessment of the incidence of carbon leakage and induced technological change due to CO2 abatement measures*. ECN.
- Stratagem Strategic Research (2004) *Het belang van het Schipholnetwerk voor het in Nederland gevestigde bedrijfsleven - Een analyse op sectorniveau*.
- Thomas, G. (2009) *Getting closer to a biofuel future*. *Air Transport World*, 49-51.
- Van den Berg, D. (2009) *Personal interview*. Taken on April 26, 2009, Schiphol.
- Van Unnik, J. (2009) *Personal interview*. Taken on May 15, 2009, Delft.
- Veldhuis, J. & Lieshout, R. (2009) *Estimating the attractiveness of airline networks: the NetCost Model*. Amsterdam, SEO Economic Research.
- Vespermann, J., Wald, A. & Gleich, R. (2008) *Aviation growth in the Middle East – impacts on incumbent players and potential strategic reactions*. *Journal of Transport Geography*, 16, 388-394.
- Weintraub, E. R. *Neoclassical Economics*. <http://www.econlib.org/library/Enc1/NeoclassicalEconomics.html>. The Concise Encyclopedia of Economics.
- Wilson, D. & Purushothaman, R. (2003) *Dreaming With BRICs: The Path to 2050*. Goldman Sachs.

Appendices

Appendix I – Carbon Leakage

Carbon leakage occurs when activities that initially take place in a country where carbon emissions are charged (abating country) are relocated to a country where no emission costs are in place (non-abating country). In this way, global emissions will be higher since the emissions cap in the abating country remains the same while additional emissions take place in non-abating countries (Davidson et al., 2008). Such effects can be considered *spillover effects* of climate policy. In general, these spillover effects can be defined as the effects of abatement measures in one group of countries on sectors in other countries. Other spillover effects include effects on trade and diffusion of technology. Sijm et al. (2004) distinguish three components of international spillovers:

1. Economic substitution effects, resulting in leakage of emissions
2. Diffusion of technological innovations
3. Political influence of industrialised countries mitigation efforts on developing countries' abatement actions

Carbon leakage corresponds to the first component of spillovers. To define it, a usable starting point is provided by the definition given by Sijm et al.: *“the effect that a part of the CO₂ reduction that is achieved by countries that abate CO₂ emissions is offset by an increase in CO₂ emissions in non-abating countries”* (Sijm et al., 2004). However, this does not clearly reflect the premise that the increase in the non-abating countries should be the result of the policy of the abating countries: otherwise all emissions as a result of the autonomous growth of the non-abating country could be considered carbon leakage as well. Therefore in this thesis the following definition for carbon leakage has been used:

The (partial) offsetting of a CO₂ emission reduction in an abating country by increasing emissions from a non-abating country as a result of shifting demand caused by carbon cost differences between the countries.

Using this definition, a quantitative definition can be formulated:

Carbon leakage [ton] = the amount of emissions in non-abating countries attributed to goods or services formerly produced in an abating country.

Sijm identifies four mechanisms or channels for carbon leakage:

1. *International trade in energy goods*: if carbon reduction policies in a certain region lead to diminishing global fossil fuel prices, this could increase the demand for fossil fuels in the rest of the world.
2. *International trade in goods and services*: the costs of certain goods and services may increase in emission reducing countries, leading to a shift in demand toward non-abating countries.
3. *International trade in factors of production*: on the long term, cost differences as a result of emission costs may lead to the international reallocation of industries.
4. *International interaction among government policies*: Policies in abating countries may influence the policies of non-abating countries by affecting the income levels and cost/benefit balances of those countries. This change could be positive or negative in terms of carbon leakage

Although all four mechanisms are applicable and likely to occur in the aviation sector on the long term, it is mainly the second category that is relevant for this research considering the scope: if the transport service as provided by airlines operating from Dubai is cheaper than the services from airlines operating from Europe, this could cause a direct demand shift. The resulting emissions by those passengers (that effectively evade the European emissions cap) represent the resulting carbon leakage. In this way, achieved emission reductions by airlines operating from Europe are offset by an increase in emissions from airlines operating from a hub like Dubai. This 'carbon-leakage' is undesirable, both from an economical and environmental point of view: it renders a threat to European aviation and negates the goal of reducing global greenhouse gas emissions.

Appendix II – Destination overlap

Table A.1: Sum of destinations (based on Kolkman and Korteweg, 2009)

<i>Region</i>	<i>Schiphol</i>	<i>Schiphol Dubai</i>	<i>& Dubai</i>	<i>Total</i>
Africa	11	11	13	35
Asia	3	17	36	56
Europe	105	31	5	141
Latin America	13	1	0	14
Middle East	3	10	21	34
North America	17	4	4	25
South Pacific	0	0	0	0
Total	152	74	79	305

From this table the following overlap in destinations between Schiphol and Dubai has been determined. On flights with a stopover it has been assumed the leg with the lowest overlap determines the total overlap.

Overlap per region:

N.America:	19,0%
Asia + ME:	81,8%
Europe:	22,8%

Overlap per market segment:

Transfer

N. America – Asia:	19,0%
N. America – EU:	19,0%
Asia – EU:	22,8%
EU – EU:	22,8%

Direct

Schiphol - N.America:	19,0%
Schiphol – Asia:	81,8%
Schiphol – EU:	22,8%

Appendix III - Weighted average distances

In this chapter the calculation of weighted average distances is elaborated. Data are based on Schiphol's annual report (Schiphol, 2007) and KLM passenger data (KLM, 2008).

Table A.2: Overview of distances for top-10 destinations per region

Intra-EU flights			
Top 10 destinations	weight [no. of pass. at Schiphol]	g.c. dist. to SHOL [km]	g.c. dist. to Dubai [km]
London	1707600	370	5479
Barcelona	1229957	1239	5177
Paris	1103025	397	5255
Madrid	971356	1458	5665
Copenhagen	749567	633	4830
Milan	655952	796	4400
Rome	652420	1294	4316
Zurich	638474	601	4769
Oslo	600038	840	5146
Stockholm	594690	1152	4765
Weighted average distances to European destinations		SHOL - EU [km]	DUB - EU [km]
		834	5089
Intercontinental flights			
Top 10 west (North America)	weight [no. of pass.]	g.c. dist. to SHOL [km]	g.c. dist. to Dubai [km]
Detroit	792291	6330	11391
New York JFK	559481	5855	11021
Minneapolis	516114	6700	11602
Toronto	447105	5996	11089
New York EWR	375292	5872	11021
Houston	360756	8056	13169
Chicago	296815	6622	11663
Washington	296160	6213	11354
Atlanta	288025	7074	12216
San Francisco	242919	8796	13028
Weighted average distances to N.America destinations		SHOL - N.America [km]	DUB - N.America [km]
		6592	11624
Top 10 east (Middle East & Asia)	Weight [no. of pass.]	g.c. dist. to SHOL [km]	g.c. dist. to Dubai [km]
Bankok	391815	9185	4884
Kuala Lumpur	383783	10201	5533
Hong Kong	376771	9299	5961
Tokyo	348546	9328	7950
Shanghai	296590	8891	6434
Tel Aviv	277090	3313	2141
Philippines	236018	10421	6917
Delhi	221968	6370	2210
Seoul	220514	8583	6800
Singapore	211410	10522	5829
Weighted average distances to Asian destinations		SHOL - Asia [km]	DUB - Asia [km]
		8708	5536

Table A.3: Overview of distances per market segment

Overview per market segment		
<i>Transfer via Schiphol</i>		
<i>Transfer N. America - Asia</i>	Total distance	Distance under ETS
Via Schiphol	15299	15299
Via Dubai	17160	0
<i>Transfer N. America - EU</i>		
Via Schiphol	7425	7425
Via Dubai	16714	5089
<i>Transfer Asia - EU</i>		
Via Schiphol	9542	9542
Via Dubai	10625	5089
<i>Transfer EU - EU</i>		
Via Schiphol	1668	1668
Via Dubai	10179	10179
Direct from/to Schiphol		
<i>Direct Schiphol - N. America</i>		
Direct from Schiphol	6592	6592
With stopover at Dubai	16797	5173
<i>Direct Schiphol - Asia</i>		
Direct from Schiphol	8708	8708
With stopover at Dubai	10709	5173
<i>Direct Schiphol - EU</i>		
Direct from Schiphol	834	834
With stopover at Dubai	10262	10262

Appendix IV – calculation of EU ETS costs

The formulas below aim to clarify how the costs of the EU ETS have been calculated in the developed model:

- 1) *EU ETS costs per passenger = emissions per passenger * emissions share to be paid for * allowance price*
- 2) *Emissions per passenger = route distance * fuel use * emissions factor / average load factor*
- 3) *Emissions share to be paid for = (Emissions cap / total emissions * auctioning share) + (total emissions – emissions cap) / total emissions*
- 4) *Total aviation emissions = emissions 2012 * (aviation growth – efficiency increase)^number of years considered*
- 5) *Actual emissions cap = initial emissions cap * annual reduction of cap ^number of years considered*

To determine the emissions per passenger, for this thesis the following methodology has been developed:

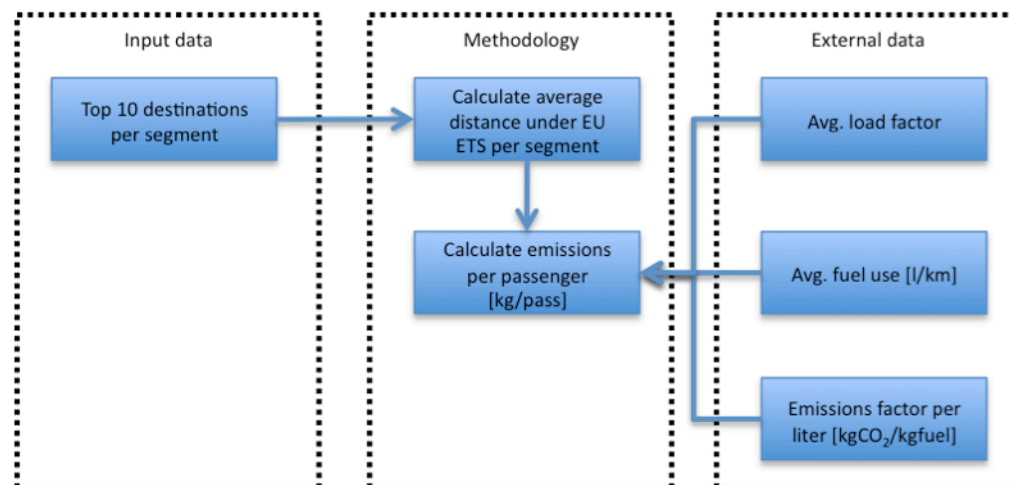


Figure A.1: methodology to determine emissions per passenger (based on Jardine, 2009)

Appendix V – Overview of static input variables

Table A.4: flight characteristics

<i>Variable</i>	<i>Unit</i>	<i>Value</i>	<i>Description</i>	<i>Source</i>
Fuel use	Litre/km	7.4	Fuel use of average aircraft per flown kilometre	(Ernst & Young, 2007)
Emissions factor per kg	kgCO ₂ /kgfuel	3.157	Average emissions of CO ₂ per kg kerosene used	(Jardine, 2009)
Density of kerosene	kg/l	0.80	Density of kerosene	(INCHEM, 1998)
Emissions factor per litre	kgCO ₂ /lfuel	2.5256	Average emissions of CO ₂ per l kerosene used	(Jardine, 2009)
Assumed aircraft capacity	# of pass	340	Average number of passengers on a flight	(Ernst & Young, 2007)
Average load factor	%	80%	Average share of airline's passenger carrying capacity that is used	(Ernst & Young, 2007)
Average load	pass/aircraft	272	Average airline's passenger carrying capacity	Calculation
Emissions per passenger per km	kg/pass/km	0.069	Emissions of CO ₂ per passenger per kilometre flown	Calculation
Average aircraft speed	Km/hr	900	Average speed of average long-haul aircraft	(KLM, 2009b)

Table A.5: sector characteristics

<i>Variable</i>	<i>Unit</i>	<i>Value</i>	<i>Description</i>	<i>Source</i>
Avg. sectoral emissions 2004-2006	Mton CO ₂ /yr	150	Average CO ₂ emissions by European aviation sector over period 2004-2006	(Bows and Anderson, 2008)
Relative emissions cap in 2012 (vs. '04-'06)	%	97%	Relative emissions cap for European aviation sector in 2012, indicated as a share of the average emissions over 2004-2006	(European Commission, 2008)
Aviation cap 2012	Mton CO ₂ /yr	145.5	Emissions cap for European aviation sector in 2012	Calculation (Bows and Anderson, 2008)
Sectoral emissions 2012	Mton CO ₂ /yr	284	Expected total CO ₂ emissions by European aviation sector in 2012	(Bows and Anderson, 2008)

Table A.6: additional data

<i>Variable</i>	<i>Unit</i>	<i>Value</i>	<i>Description</i>	<i>Source</i>
Unit revenue per RPK	€/km	0.0875	total revenue divided by RPK (Revenue Passenger Kilometre)	(KLM, 2009b)
Total passengers transported at Schiphol in 2008	kp/year	47430	Including transit-passengers	(Schiphol Group, 2008)
Total emissions in the Netherlands under EU ETS	Mt/yr	84	Total emissions by sectors falling under the EU ETS	(European Commission, 2006b)

Appendix VI – Estimation of scenario-specific input variables

11.1.1. Aviation auctioning share

This refers to the share of allowances under the emissions cap for which the aviation sector has to pay by means of auctioning. The remaining allowances under the cap are distributed for free ('grandfathering'). Initially, the EC proposed full auctioning as of 2013. However, major disagreements on this issue arose between stakeholders. Under the final compromise, this was lowered to only 15% initial auctioning in 2012 (Euractiv, 2008). However, this share is quite low compared with most other sectors under EU ETS, and the EU has announced "*this percentage may be increased as part of the general review*" which takes place in 2013 (European Commission, 2008). Therefore it is well thinkable that this share will be raised. Anticipating this raise, most impact studies²⁷ on the EU ETS have assumed auctioning shares between 15% and 100%. However, it seems highly unlikely that this share will be more than doubled during phase III of the EU ETS. Therefore a range of 15-30% has been assumed.

11.1.2. Annual reduction of cap

In the EC directive, the total yearly quantity of allowances to be allocated to aircraft operators is set to 95% compared with the average annual emissions in 2004-2006. In the current directive this percentage is fixed for the whole third trading period (2013-2020), meaning the annual reduction is zero. However, this percentage will be subject to the general review in 2013 as well (European Commission, 2008). Considering the fact that the EU-wide emissions cap is cut by 1,74% annually, it is possible that this yearly reduction will then be applied to the aviation sector as well. In that case the annual reduction will be 1,74%.

11.1.3. Efficiency increase per passenger

This variable refers to the efficiency in terms of CO₂ emissions per passenger-kilometre (PKM): It is an aggregate variable for several technical, operational and policy variables that each can result in a relative reduction of emissions. The overview below gives an overview of possible measures for each category.

Technical

Blending of biofuels: although technically possible, it is very unlikely that planes that fly solely on biofuels will be taken into commercial use in the considered period. However, biofuels could be commercially available for blending as soon as 2011, most likely on the basis of jatropha or algae. Still, the actual availability will depend on various factors like certification procedures and the production capacity (Thomas, 2009).

More efficient planes: due to fleet renewal programs quite significant emission reductions can be achieved. Furthermore other measures like the use of modern engines or weight-

²⁷ For example CE Delft & MVA Consultancy assume either 10% or full auctioning, The EC impact assessment assumes 10%, 20% or 40% and Ernst & Young assume either 20% or 40% auctioning.

reduction programmes with regard to the paint or carriages can together result in emission reductions of up to 17% (KLM, 2009a).

Altogether, these measures can significantly increase the fuel efficiency of airplanes, even in the short term. According to the Group on International Aviation Climate Change (GIACC), an efficiency increase of up to 2% annually is feasible (Green Air Online, 2009).

Operational

Increase load factors: this refers to measures that result in a higher load factor, for example adjusting the schedule in such a way that load factors increase at the expense of longer stopover times (Bows and Anderson, 2008).

Increase efficiency at airport: this includes all measures that decrease the emissions of aircraft at or near the airport, for example by reducing taxiing time, waiting and circling time and reducing use of the auxiliary power unit (Bows and Anderson, 2008).

Policy

Single sky agreement: the Single European Sky (SES) agreement, which is likely to come into force before phase III of the EU ETS, allows airplanes to fly more direct, efficient routes: currently, the European airspace is divided in 27 different systems, each under control of national governments, as depicted in figure A.2 below. This forces airlines to zigzag between airspaces, resulting in inefficient routes, thus increasing emissions.



Figure A.2: current division of European Airspace in 27 separate systems (taken from KLM, 2009a)

The SES aims to establish cross-border cooperation between national air navigation providers to eliminate the current fragmented approach (Eurostat, 2009). This should result in a more harmonized and efficient utilisation of airspace, as shown in figure A.3 below.



Figure A.3: harmonized approach under Single Sky agreement (taken from KLM, 2009a)

Altogether, there is a significant abatement potential for increasing the fuel efficiency in terms of CO₂ emissions, mainly by the use of biofuels, increasing the load factor and improving the route and airport efficiency. In the impact assessment by the European Commission (2006), it is estimated that an annual efficiency increase between 1 to 2 % is feasible. This is acknowledged by various other studies with estimations between 1-1,47% (Scheelhaase and Grimme, 2007) and 1% (Boon et al., 2007). Thus, in the scenario analysis an annual efficiency increase between 1% and 2% is assumed.

11.1.4. Aviation growth

Since 1960, the aviation sector has been one of the fastest growing sectors of the world economy: air traffic has grown almost 9% per year on average, 2.4 times the global average GDP growth rate (Bows et al., 2005). Although the current financial crisis is expected to cause a limited reduction of passenger traffic in 2009 and limited growth until 2011, on the long term the growth rate is expected to return to its old pace (IATA, 2008). Therefore, in this study a growth rate between 5% and 7% is assumed.

11.1.5. Allowance price

This refers to the price of a EU Allowance Unit (EUA), which gives the owner the right to emit one tonne of CO₂. Since the price of an allowance is market driven, it is very complex to predict: it depends on various factors like the size of the emissions cap, the abatement potential of each included sector, economic growth, and other factors (Gagelmann, 2002). Furthermore historical data provides little guidance, since the conditions for the period analyzed in this study are significantly different then in previous phases. Therefore estimates from several leading studies are used. First of all it should be noted that the EC impact assessment uses rather low estimates, with a price of either €6 or €30. Most other studies

have assumed values between €15 and €100, with a large share assuming €30 as base scenario. Therefore in this study values of €30 and €60 has been used.

11.1.6. Dubai destination growth

As described in the previous chapter, Dubai airport and Emirates airlines are heavily expanding their airport and fleet. This will surely lead to increased network coverage, also on the North-American market where Dubai currently serves a limited number of destinations (O'Connell, 2006). Taking the percentages in section 4.4 as a starting point, in this study two possible growth scenarios for route overlap are taken into account: limited growth where it is assumed that the overlap grows 2% annually, and aggressive growth assuming an annual overlap growth of 5%.

Appendix VII – Sensitivity analysis

Table A.7: overview of inputs and outputs of scenario analysis

Input variable	Base value	Base value -10%		Base value +10%	
		Δ tot.pass	Δ pass SHL-ICA east	Δ tot.pass	Δ pass SHL-ICA east
Annual growth in destinations	2%	-7,58%	-5,49%	7,49%	5,42%
Flight time	-0,264	6,18%	-3,45%	-4,90%	3,37%
Average aircraft speed	900	-5,37%	3,74%	5,57%	-3,13%
ICA West-East distribution	0,43	-5,19%	N.A.	5,19%	N.A.
Average load factor	272	-5,07%	-6,52%	4,02%	5,29%
Fuel use	7,4	4,42%	5,82%	-4,56%	-5,87%
Emissions factor per kg	3,157	4,42%	5,82%	-4,56%	-5,87%
Allowance market price	30	4,42%	5,82%	-4,56%	-5,87%
Airfare	-0,0195	4,42%	5,82%	-4,56%	-5,87%
Sectoral emissions 2012	284	1,88%	2,45%	-1,55%	-2,01%
Avg. sectoral emissions 2004-2006	150	-1,71%	-2,21%	1,69%	2,21%
Relative emissions cap in 2012	0,97	-1,71%	-2,21%	1,69%	2,21%
Annual aviation growth	0,05	0,86%	1,12%	-0,82%	-1,06%
Aviation auctioning share	0,15	0,30%	0,39%	-0,30%	-0,39%
Annual red. of aviation emissions cap	-1,74%	0,16%	0,21%	-0,16%	-0,21%
Autonomous efficiency increase	-0,01	-0,11%	-0,14%	0,11%	0,15%
Stopovers	-0,6608	0,00%	-5,03%	0,00%	4,86%

The number of stopovers needs clarification: the total amount of passengers switching to Dubai does not seem sensitive to the valuation of stopovers. This can mainly be explained by the fact that for transfer passengers, the number of stopovers is equal when flying through Dubai instead. Only direct passengers will incur an additional stop when choosing to fly through Dubai, which explains why the number of direct Asia travellers switching to Dubai is inversely related to the number of stopovers.

Appendix VIII – Other airports

As shown in chapter 7, whether an airport in Europe can be expected to incur a significant redistribution of passengers to Dubai largely depends on the relative share of certain market segments. Although not part of the scope of this research, in this chapter a short overview is given on the projected impact on other main European airports. Given the fact that their geographical location is comparable to Schiphol (at least on the scale of European flight), it can be expected that the EU ETS will mainly impact their Asian routes. Furthermore, when comparing the four main airports, it can be noticed that Schiphol has only a minor share of flights to Asia, as shown in the figure below:

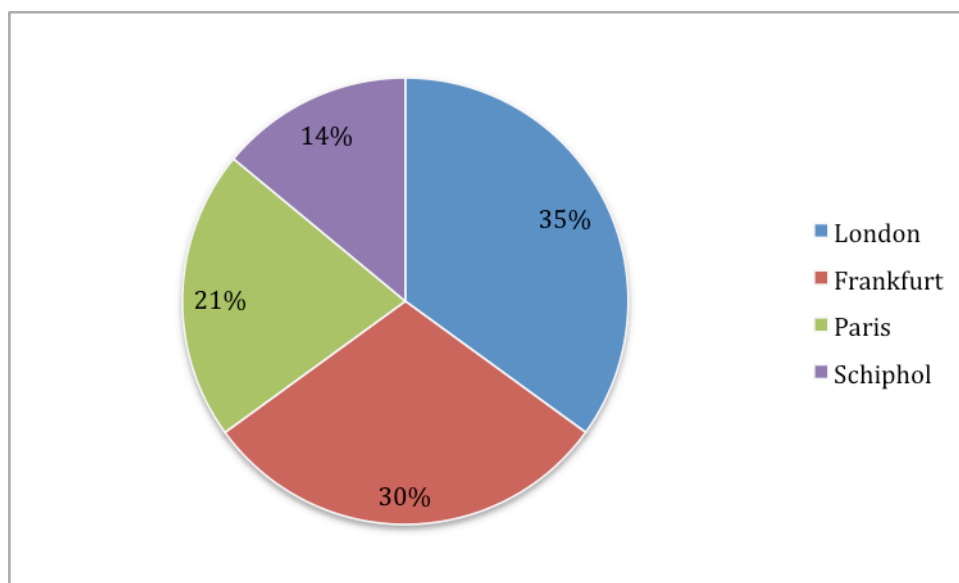


Figure A.4: share of four main European airports on Asian market segment (based on Stratagem Strategic Research, 2004)

This figure clearly shows that the other three main European airports (London Heathrow, Paris Charles De Gaulle and Frankfurt) have a large share of Asian flights, in which there will likely be a significant impact of the EU ETS.

Annex A – Scientific paper

Modelling airport choice behaviour between two airports

The use of a binary choice model

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Abstract

The increased use of the hub-and-spoke system and the ongoing liberalization of the aviation sector have led to an increased competition between airlines. As a result, nowadays passengers can often choose between different carriers to reach their destination, with a stopover at the carrier's main hub. To model air travel choice behaviour in this specific situation, a new approach is needed. The methodology described in this paper presents a straightforward way to calculate the distribution of passengers between two competing airport hubs as a function of route attributes and passenger preferences. To this end a binary discrete choice model has been developed on the basis of passenger preferences acquired from a study by Hess. The model has been applied to model the distribution between Schiphol and Dubai for several exemplary routes, and the outcomes indicate the model performs as expected. However, the static nature of the model limits the validity of the outcomes. Therefore theoretical and empirical research is needed on the interactions between capacity constraints and passenger demand.

Keywords: Hub airport, passenger route choice, distribution, logit model, route attributes, passenger preferences

1. Introduction

The increasing use of the 'hub-and-spoke' system, as opposed to 'point-to-point' flights, has led to a strong increase in the number of 'city pairs'²⁸ connected through an airport (Kanafani and Ghobrial, 1985). Meanwhile, the ongoing liberalization of the aviation market has resulted in more competition between airlines. Altogether, passengers face an increasing choice of connections. In practice, on many 'city pairs' multiple carriers now compete to offer a connection with a stopover at their own 'main hub' (Dennis, 1999). Although many studies have been performed on passenger route choice, there is still little literature available on how to model this specific route choice. This paper describes a straightforward method to calculate the distribution of passengers between two possible hub airports as a function of the properties of both routes.

2. Discrete choice model

The choice described above can be considered a *discrete choice*: individuals have to select an option from a finite set of alternatives. It is generally assumed that this can best be modelled with a *disaggregate demand model*, which is based on observed choices made by individual travellers. This type of model has been chosen, because it can be expected to result in a more realistic model compared to *aggregate demand models*, which are based on observed

relations of groups of travellers, or on average relations at a zonal level (De D. Ortuzar and Willumsen, 1994).

It should be noted that the passenger route choice can not be adequately modelled by 'all or nothing' models that assume all passengers simply choose the cheapest route: this choice depends on a combination of fare and many other *attributes* that together make up the quality of each alternative route option. From a modelling point of view, not all these attributes are known, and of those that are known not all are measurable. Furthermore, passengers might not be aware of all these service attributes. Therefore, to deal with this lack of information a probabilistic model should be used (Alamdari and Black, 1992). This probabilistic model exists of a deterministic and a stochastic component. Both components are described in the next sections.

Deterministic component

In general, discrete choice models postulate that (De D. Ortuzar and Willumsen, 1994):

"The probability of individuals choosing a given option is a function of their socioeconomic characteristics and the relative attractiveness of the option"

This attractiveness of alternatives is represented by the concept of *utility*²⁹. Accordingly, for this research a *utility-*

²⁸ This refers to all possible 'one-stop city pairs': cities connected with each other with one stopover at the connecting hub (Schiphol Group, 2007d).

²⁹ Many studies in the field of transport (e.g. MVA Consultancy, 2006) use the concept of *generalized costs* instead of utility. This is

based discrete choice model has been used, which postulates, in accordance with neoclassical economics (Chorus, 2009):

- 1) An alternative can be described as a *set of attributes* (e.g. travel time, airfare and number of stopovers)
- 2) Travellers choose the alternative with the highest utility

Using the Lancasterian utility theory, in this study it is assumed this utility is a *linear additive function* of these attributes and the parameters (coefficients) that represent the preferences of passengers (Chorus, 2009).

Thus, the observed utility of a route alternative can for example be defined as the following linear combination of variables:

$$V_A = \beta_{current} + \beta_{fare} \times fare_a + \beta_{flight_time} \times flight_time_a$$

(1)

Where

V_A is the *observed utility* of route alternative A.

$\beta_{current}$ is the *alternative-specific constant (ASC)*: this represents the net influence of all unobserved or not explicitly included characteristics of an alternative. For example, these could include characteristics that make an airport more attractive for travellers, like multi-lingual personnel or a large vat-free shopping zone.

β_{fare} and β_{flight_time} are *coefficients* that give the relative influence (or *weight*) of attributes like fare and flight time. Put differently, they capture the (dis)utility associated with an increase by one unit (1 minute or €1) in fare or flight time (Hess, 2008).

$fare_a$ and $flight_time_a$ are *attributes* of route alternative A, and in this case refer to the airfare and the flight time of alternative A.

Stochastic component

As described in the beginning of this section, it is impossible to determine the individual utility of each alternative for each traveller flawlessly, which is why an *error term* is always included. Thus, U_a (the net utility U of alternative a) = V_a (the observed utility) + ϵ (the error term). This error term is usually *extreme value type-I* or *Gumbel* distributed. By using a *Multinomial Logit Model (MNL)*, an error term drawn from this distribution is automatically included in the function (De D. Ortuzar and Willumsen, 1994).

Multinomial Logit function

a comparable concept, so in this study only the concept of utility has been used.

To predict what share of individuals will choose a certain alternative, the value of its utility must be contrasted with those of other alternatives and transformed into a probability value between 0 and 1. This will represent the chance that an individual will choose this alternative. To derive this probability value several mathematical transformations exist, but as described in the previous paragraph using a MNL model is most suitable since it takes into account the error term. Since a choice between two options is modelled, a *binary logit model* is used in this study (De D. Ortuzar and Willumsen, 1994):

$$P_a = \frac{\exp(V_a)}{\exp(V_a) + \exp(V_b)} \quad (2)$$

Where

P_a is the probability that alternative A is chosen.

V_a is the observed utility of alternative A.

This probability equals the share of all individuals that will choose alternative A. To illustrate this formula, the exemplary curve below shows the share of passengers choosing alternative A as a function of $V_b - V_a$.

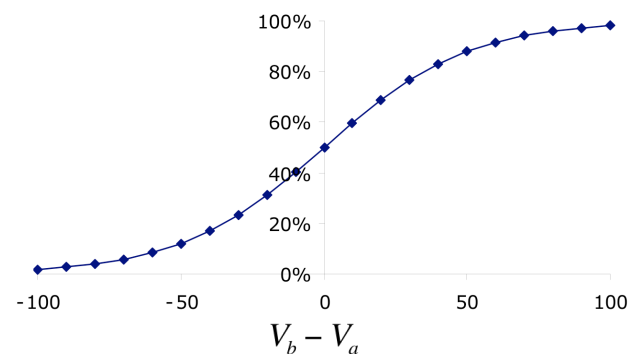


Figure 1: exemplary curve showing share of passengers choosing alternative A (taken from MVA Consultancy, 2006)

3. Passenger preferences

As described in the previous section, by using a MNL model an error term is implicitly included, thereby compensating for measurement errors and attributes that are not known or deliberately left out of the model. This makes it possible to select only a limited set of attributes. In this section it is explained how relevant attributes has been selected, and how values for these attributes have been acquired from another study that is expected to most closely resemble the case of this research. This approach has been chosen because this paper aims to provide a method to predict passenger route choice in a straightforward way, without the need to hold a survey to obtain passenger preferences. However, the use of data from another study, which has

been acquired in a different setting and airport implies two crucial assumptions (De D. Ortuzar and Willumsen, 1994):

3. Constants from the other study are ignored, thereby implicitly assuming the ASC is equal (both airports are equal in non-observed characteristics)
4. Coefficients from the other study will be used directly in this research, thereby explicitly assuming that the effects of attributes on the choice behaviour in the Schiphol setting is equal to that in the original study

Identifying relevant attributes

Many studies have been performed to identify which ‘level-of-service’ attributes influence passengers’ choices. A study by Loo (Loo, 2008) focuses on passengers’ airport choice in multi-airport regions (MARs) and identifies an extensive list of attributes, as shown below:

Table 1: ‘Level-of-service’ attributes (adapted from Loo, 2008)

Primary attributes	Flight characteristics	Airport characteristics
Airfare	Flight frequency In-flight travel time Number of stops Transfer arrangements Congestion/punctuality Airlines Aircraft type	Airport access time Access cost Access mode Parking facilities Check-in facilities Lounge, restaurant and shopping facilities Transfer facilities Baggage, customs and immigration facilities Airport tax or passenger charge

In this paper, only attributes that differ between two route options are taken into account: for example, this implies that attributes of the origin or destination airport are not taken into account since passengers have a fixed origin and destination airport. In addition, parameters like average schedule delay, frequency and airport/airline ranking are assumed to be identical for all alternatives and thus not included in the model, either because no data is available or an attribute is expected to be irrelevant. This way, the following three route attributes have been selected:

- Airfare
- Flight time
- Number of stopovers

In the next sections it is explained how the relative influence of each attribute has been determined, and how values of attributes are calculated in the developed model.

Determining relative influence of attributes

As explained in the previous section, for this research data from an existing study has been used. In this section the choice of an appropriate study is elaborated. Since the focus

of this research is on a discrete, binary choice between two route options, coefficients from a stated preferences study where two possible alternatives are presented to travellers is most appropriate.

When comparing existing studies, it should be noted that with the rise of the Internet, the way travellers choose their airline and route has drastically changed: instead of booking through a travel agent who presents a few possible options, travellers use the internet to compare all possible routes on criteria like price, travel time and number of stopovers. As a result, older studies have little predictive values today. In addition, since the binary logit model formulated above is a *linear additive function*, only coefficients from studies using a linear logit model are compatible.

Therefore, in combination with the fact that the outcomes of a recent, stated preferences study will best represent passenger preferences in the case study, several appropriate studies have been identified: a study on air travel behaviour modelling by Hess (2007), a study on air travel choices by Ishii et al. (2009) a study on passenger’s airport choice by Loo (2008) and a study on airport and airline choice by Pels et al. (2001). After a thorough comparison, the study by Hess has been chosen because it provides exactly the coefficients needed and does not distinguish between different types of travellers (e.g. leisure and business), which would require another, more complex modelling approach. The table below gives an overview of these coefficients:

Table 2: overview of coefficients for route attributes (adapted from Hess, 2007)

Attribute	Coefficient
Flight time [hrs]	-0.264
Airfare [€]	-0.0195
Number of stopovers [discrete]	-0.6608

Validation of coefficients

To validate the coefficients acquired in the previous paragraph, the ratios between airfare and the other two coefficients have been calculated to express the ‘value’ of a coefficient: the value of time (VoT) is €13.54 per hour and the value of a stopover is €33.89 per stopover. These ratios indicate what price passengers are willing to pay for one hour less flight time or for a direct flight, based on the sample group analyzed in the stated preferences study by Hess. These ratios have been compared to several other studies that focus on passenger route choice: MVA Consultancy uses a segmented approach and indicates a VoT of €20 for leisure passengers and €50 for business passengers (MVA Consultancy, 2006). Stratagem assumes a uniform VoT of €27.86 (Stratagem Strategic Research, 2004). Regarding the value of a stopover, no other recent studies could be found. Therefore an older study by Kanafani et al. has been used to determine the value of a direct flight in terms of time: it shows a direct flight is worth 1.74 hours of flight time (Kanafani and Ghobrial, 1985),

versus 2.50 in the used study of Hess. Thus, it can be concluded that the ratios in Hess' study are plausible for leisure passengers. However, the VoT for business passengers is considerably higher, which would result in a lower sensitivity to cost differences caused by the EU ETS. This is addressed in the conclusions. In addition, it should be noted that the included coefficient for the number of stopovers includes the extra travel time involved: as shown, a stopover equals 2.5 hours of travel. This is comparable to the assumptions by MVA Consultancy (2006), who estimate a stopover equals 1 hour of travel time, multiplied by an 'inconvenience penalty' between 2 and 3.

Application of coefficients

Based on these coefficients, the following formula can be derived to describe the observed utility of a given alternative:

$$V_A = -0,264 \times fare_a - 0,0195 \times flight_time_a - 0,6608 \times stopovers_a \quad (3)$$

Using the calculated observed utility of both alternatives, the probability of passengers choosing one alternative (including the error term) is then calculated by applying the binary logit model (1) provided earlier in this chapter.

4. Case study

To test the developed model, it has been applied to calculate the distribution between Schiphol and Dubai on several exemplary routes. The tables below show the properties of those routes via Schiphol and Dubai. It should be noted though that the values of attributes are estimates that serve only to demonstrate the model.

Table 3: attributes of New York - Mumbai

Connecting airport	Flight time	Airfare	Stopovers
Schiphol	17.0	1389	1
Dubai	19.1	1339	1

Table 4: attributes of London - Mumbai

Connecting airport	Flight time	Airfare	Stopovers
Schiphol	10.6	866	1
Dubai	11.8	835	1

Table 5: attributes of Amsterdam - Mumbai

Connecting airport	Flight time	Airfare	Stopovers
Schiphol	9.7	780	0
Dubai	11.4	762	1

After applying these values in the developed model, the following distribution was predicted by the model:

Table 6: predicted shares of hub airports on exemplary routes

Route	Schiphol	Dubai
New York - Mumbai	39.3%	60.7%
London - Mumbai	50.8%	49.2%
Amsterdam - Mumbai	70.9%	29.1%

Although it is not possible to verify these values independent of the developed model, they seem probable given the route attributes and the assessment of the author. Further research should indicate whether the model's predictions are reliable.

5. Conclusion and discussion

This paper has presented a straightforward method to calculate the distribution of passengers between two hub airports on the basis of their preferences and three route attributes: flight time, airfare and number of stopovers. To this end, values for passenger preferences have been adopted from a study by Hess (2007). The outcomes of the case study, where the model has been applied to calculate the distribution between Schiphol and Dubai for several routes, indicate the model functions as expected.

However, the static modelling approach used has certain inherent shortcomings: it presumes the distribution of passengers is solely dictated by passenger demand. In reality, there could be capacity constraints on certain routes, thereby influencing the passenger distribution. In addition, this capacity cannot be adapted quickly because of fixed costs associated with investments falls (Boon et al., 2007). This holds true especially in the aviation sector, for example because of very long lead times between the order and delivery of an aircraft. As a result, the developed model is mainly useful to calculate a *hypothetical distribution* of passengers, regardless of capacity constraints. Therefore additional theoretical and empirical research is needed on the interactions between capacity constraints and passenger demand.

In addition, the model currently does not allow for the prediction of demand effects as the result of price increases. To this end, future research should aim to integrate the price elasticity of demand in the model.

References

- Alamdari, F. E. & Black, I. G. (1992) *Passengers Choice of Airline under Competition - the Use of the Logit Model. Transport Reviews*, 12, 153-170.
- Chorus, C. (2009) *Personal interview*. TU Delft.
- De D. Ortuzar, J. & Willumsen, J. G. (1994) *Modelling transport*, John Wiley & Sons.
- Dennis, N. (1999) *Competition between airports for long-haul traffic from Europe*.

- Hess, S. (2007) *Posterior analysis of random taste coefficients in air travel behaviour modelling. Journal of Air Transport Management*, 13, 203-212.
- Hess, S. (2008) *Treatment of reference alternatives in stated choice surveys for air travel choice behaviour. Journal of Air Transport Management*, 14, 275-279.
- Kanafani, A. & Ghobrial, A. A. (1985) *Airline hubbing--Some implications for airport economics. Transportation Research Part A: General*, 19, 15-27.
- Loo, B. P. Y. (2008) *Passengers' airport choice within multi-airport regions (MARs): some insights from a stated preference survey at Hong Kong International Airport. Journal of Transport Geography*, 16, 117-125.
- MVA Consultancy (2006) *Consequences for the Dutch Aviation Sector of Inclusion in the European Emission Trading Scheme.*
- Schiphol Group (2007) *Werken aan de toekomst van Schiphol en de regio.*
- Stratagem Strategic Research (2004) *Het belang van het Schipholnetwerk voor het in Nederland gevestigde bedrijfsleven - Een analyse op sectorniveau.*